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interim performance criteria for solar heating and combined heating/cooling systems and dwellings

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FOREWORD

This interim performance criteria (IPC) document will be used for the design, development, technical evaluation and procurement of the solar heating and cooling systems and the dwellings to be used in the solar heating and cooling demonstration program authorized by Public Law 93-409, the "Solar Heating and Cooling Demonstration Act of 1974."

These interim criteria are related primarily to technical performance and do not directly address economic considerations, energy conservation or the selection of sites. These considerations are dealt with separately in the demonstration program.

The Department of Housing and Urban Development (HUD) and the National Bureau of Standards (NBS) are indebted to the many organizations, Government agencies, consultants, and individual professionals who have contributed to the preparation of this document.

SI CONVERSION UNITS

In view of the present accepted practice in this country for building technology, common U.S. units of measurement have been used throughout this document. In recognition of the position of the United States as a signatory to the General Conference on Weights and Measures, which gave official status to the metric SI system of units in 1960, assistance is given to the reader interested in making use of the coherent system of SI units by giving conversion factors applicable to U.S. units used in this document.

Length

1 in = 0.0254* meter

1 ft = 0.3048* meter

Area

1 in^2 = 6.4516* x 10^{-4} $meter^2$

1 ft^2 = 0.09290 $meter^2$

Volume

1 in^3 = 1.638 x 10^{-5} $meter^3$

1 gal (U.S. liquid) = 3.785 x 10^{-3} $meter^3$

1 liter = 1.000* x 10^{-3} $meter^3$

Mass

1 ounce-mass (avoirdupois) = 2.834 x 10^{-2} kilogram

1 pound-mass (avoirdupois) = 0.4535 kilogram

Pressure or Stress (Force/Area)

1 inch of mercury (60°F) = 3.376 x 10^3 pascal

1 pound-force/$inch^2$ (psi) = 6.894 x 10^3 pascal

Energy

1 foot-pound-force (ft-lbf) = 1.355 joule

1 Btu (International Table) = 1.055 x 10^3 joule

Power

1 watt = 1.000* x 10^7 erg/second

1 Btu/hr = 0.2930 watt

Temperature

°C = 5/9 (Temperature °F - 32)

*Exactly

INTRODUCTION

Background

Public Law 93-409, the Solar Heating and Cooling Demonstration Act of 1974, provides for "the demonstration within a three-year period of the practical use of solar heating technology, and ... the development and demonstration within a five-year period of the practical use of combined heating and cooling technology." Under the provisions of the Act, the Department of Housing and Urban Development (HUD) has utilized the services of the National Bureau of Standards (NBS) to develop this document containing interim performance criteria for the design and evaluation of solar heating and cooling systems to be demonstrated by HUD in residential construction.

Objectives

These interim criteria have the following objectives:

1. To provide designers, manufacturers and evaluators with the technical performance criteria that will be used for the solar heating and cooling demonstration program.

2. To establish technical performance levels that will be used for the evaluation and procurement of dwellings, systems, subsystems, components and elements for the the solar heating and cooling demonstration program.

3. To provide a basis for the development of more definitive performance criteria at a later date.

Scope

The interim performance criteria given for hardware related items such as heating systems, combined heating and cooling systems and their various subsystems, components and elements are intended to:

1. establish minimum levels for health and safety that are consistent with those given in the HUD Minimum Property Standards (MPS) for single family and multifamily housing and the ANSI A119.1 Standard for Mobile Homes.

2. ensure that the proposed heating, combined heating and cooling, and domestic hot water systems are capable of providing minimum levels of performance consistent with those given in the MPS,

3. verify that proposed systems, subsystems, components and elements are capable of providing their design performance levels, and

4. ascertain that the systems, subsystems, components, and elements are durable, reliable, readily maintainable and generally constructed in accordance with good engineering practice.

For conventional systems, subsystems, components and elements used in the solar demonstration program, compliance with the requirements of the MPS or ANSI A119.1 is deemed evidence that the systems, subsystems, components and elements are durable, reliable, readily maintainable and constructed in accordance with good engineering practice. Nonconventional systems, subsystems, components and elements which are not discussed in the MPS or other applicable codes and standards will be evaluated by means of these interim performance criteria to ascertain that they are reasonably reliable, durable, maintainable and capable of providing their rated output.

The criteria given in this document for the dwellings, in which the solar energy systems will be used, and their sites are supplementary to the provisions of the HUD MPS for single family and multifamily housing, and the ANSI A119.1 Standard for Mobile Homes in the case of mobile homes. These supplementary criteria are intended to deal with the special needs of housing designed for solar energy systems.

The interim performance criteria are intended to be flexible in order to allow freedom of design and encourage innovation in keeping with the intent of Public Law 93-409.

Organization and Format

This interim document is organized on the basis of performance criteria for the complete building heating and cooling system. Performance criteria that are uniquely applicable to individual subassemblies of the system follow the general system requirements in each performance area. Since it is recognized that subassemblies (such as the collectors and storage containers) may be manufactured independently, indexing of the specific performance requirements that are applicable to the various subassemblies of the total system is provided.

All performance statement entries are presented in the Requirement, Criterion, Evaluation and Commentary format. The Requirement is a qualitative statement giving the user need or expectation for the item being addressed. It is a general statement of what the assembly shall be able to do. The Criterion is generally a quantitative statement giving the level of performance required to meet the user need or expectation for the item being addressed. The one or more criteria associated with each requirement state the considerations which are necessary to meet the requirement. Due to limitations in the state-of-the-art, a quantitative statement is not always contained in each criterion. In other criteria, quantitative statements have been intentionally omitted where these values will be provided by the designer. Evaluation sets forth the methods of test and/or other information upon which an evaluative judgment of compliance with a criterion will be based. It states the standards, inspection methods, analyses, review procedures, historical documentation, and/or test methods which may be used in evaluating whether or not the system and its subassemblies as designed comply with the criterion. It is expected, in many cases, that the review of documentation of in-use performance, or engineering analysis, will be used as evaluative tools in lieu of testing. Commentary provides background for the reader and presents the rationale behind the selection of specific data presented in the Requirement, Criterion or Evaluation. The Commentary is intended for informational purposes, and is therefore not mandatory.

The document is divided into two parts. The first part, Systems and Components (Chapters 1 through 6) deals with interim performance criteria for heating, cooling, and domestic hot water systems and their subassemblies. The second part, Dwellings and Sites, (Chapters 7 through 13) presents performance criteria dealing with the interactions between the solar energy system and its surrounding environment, the dwelling and site. These performance criteria provide for integrating the dwelling and site with the system and its components without seriously degrading the environment or impairing the normal function of the dwelling and its components.

Both parts of the document are organized on the basis of the first six performance attributes listed below. An additional attribute, Visual Characteristics, is considered under Dwellings and Sites.

1. Functional performance statements are used to evaluate the ability of systems and their subassemblies to operate and provide their rated output. The ability of the solar heating system to maintain the dwelling at a specified temperature under a given set of outdoor conditions is an example of a functional consideration.

2. Mechanical performance statements treat the mechanical design and performance of the solar energy systems and their subassemblies. Factors such as the ability of the system to withstand normal design service conditions, e.g., pressure and temperature, are considered under this category.

3. Structural performance statements deal with the ability of systems and subassemblies to maintain their structural integrity under in-service and extreme conditions. Factors such as wind, snow and seismic loads are considered under this category.

4. Safety deals with the mitigation of hazards that could result in property damage or injury and death. Hazards such as those due to fragile, toxic and/or flammable materials are considered under this category.

5. Durability/Reliability relates to the ability of systems and their subassemblies to perform designed functions for a specified interval under actual use conditions. Corrosion and thermal degradation are typical durability/reliability related items.

6. Maintainability deals with the ease with which systems and their subassemblies can be maintained in good operating condition for extended periods of time. Routine scheduled maintenance, corrective maintenance, replacements and repairs are considered under this category. Accessibility is an important maintainability consideration.

7. Visual Characteristics deals with the dwellings, the solar heating and cooling systems, and their various subassemblies from an architectural point of view. For example, in addition to a solar collector subsystem being compatible with the dwelling on which it is installed, the entire building should be compatible with the characteristics of the neighborhood where it is located.

The various systems and subsystems treated in the document are as follows:

The heating (H) system is the complete assembly of subsystems and components necessary to convert solar energy into thermal energy and use this energy in combination with auxiliary energy, where required, for heating purposes.

The combined heating and cooling (HC) system is the complete assembly of subsystems and components necessary to convert solar energy into thermal energy and use this energy in combination with auxiliary energy, where required, for heating and cooling purposes. (Where cooling is included, nocturnal radiation, evaporative cooling and/or other means may be used in combination with, or in lieu of, heat actuated cooling.)

The domestic hot water (DHW) system/subsystem is the complete assembly of subsystems and components necessary to convert solar energy into thermal energy and use this energy in combination with auxiliary energy, where required, to provide hot water in the building. It may either be integrated directly into the H or HC systems or be completely separate from them. The term "subsystem" applies when the DHW system is integrated into the H or HC systems.

The energy transport subsystem includes those portions of the H, HC or DHW systems which transport energy throughout the systems. Heat transfer from the collector to the point of use is accomplished through the energy transport subsystem.

The control subsystem comprises all of the devices and their electrical, pneumatic or hydraulic auxiliaries used to regulate the processes of collecting, transporting, storing, and utilizing energy in response to the thermal, safety, and health requirements of the building occupants.

The auxiliary energy subsystem utilizes conventional energy sources both to supplement the output provided by the solar energy systems as required by the design conditions, and to provide full energy backup requirements during periods when the solar H, HC or DHW systems are inoperable.

The collector subsystem serves the primary function of absorbing solar radiation, converting it into useful thermal energy, and transferring the thermal energy to a heat transfer fluid.

The storage subsystem serves the primary function of storing thermal energy so that it can be used when required. Specific designs may utilize hot and/or cold storage.

This interim document is not final in nature. With the present state-of-the-art there will be a need for frequent updates to readjust levels of acceptability for both systems and components. A major reason for including a commentary in the presentation is to assure a workable process of updating these interim performance criteria by establishing the basis for selection of performance levels and methods of evaluation so that, when questions arise as to the basis for a particular criterion, the reader will have available the rationale behind the criteria.

contents

SYSTEMS AND COMPONENTS

systems and components

1.1 Requirement — H and HC system performance. The heating (H) and combined heating and cooling (HC) systems shall be capable of collecting and converting solar energy into thermal energy. The thermal energy shall be used to meet the total energy needs for space heating and cooling of residential dwellings in combination with storage and auxiliary energy, as required. Methods of cooling such as nocturnal heat radiation, evaporation or heat actuated air conditioning may be used, where appropriate.

1.1.1 Criterion — Heating design temperatures. The heating system shall be designed to maintain the indoor temperature at 70°F for 97 1/2 percent design winter temperatures[1]* for the geographic area(s) in which the system is to be installed.

Evaluation — Examination of climatic data, engineering review of drawings, specifications and calculations based upon ASHRAE analytical methods.

Commentary — It is the intent that the system be designed, fabricated, installed and operated in accordance with good HVAC engineering practice. Generally, the system should be capable of performing at levels not less than those specified in the HUD Minimum Property Standards (MPS) (Single Family, 4900.1[7], Multifamily, 4910.1[8] and/or the Manual of Acceptable Practices, 4930.1[9]).

The 70°F and 97 1/2 percent are residential heating design values reflecting the consensus of industry, government, and other interested representatives working through the ASHRAE Standards Committee to develop a standard on "Energy Conservation in New Building Design (ASHRAE Proposed Standard 90P)."

Analytical and specification methods to determine heating and cooling loads for maintaining comfort conditions in residential dwellings are described by ASHRAE[2] [3] [4], and others [5] [6].

1.1.2 Criterion — Cooling design temperatures. The cooling system shall be designed to maintain the average indoor temperature at 78°F dry bulb for outside 2 1/2 percent summer design dry bulb temperatures [1] for the geographic area(s) in which the system is to be installed. The design shall include the methods of heat rejection if required for equipment operation.

Evaluation — Examination of climatic data, engineering review of plans, specifications and calculations based upon ASHRAE analytical methods.

Commentary — The 78°F and the 2 1/2 percent are residential design cooling values reflecting the consensus of industry, government, and other interested representatives working through the ASHRAE Standards Committee to develop a standard on "Energy Conservation in New Building Design (ASHRAE Proposed Standard 90P)."

Typical procedures for determining cooling loads have been developed by ASHRAE [2] [3] [4], and others [5] [6].

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*Numbers in [ ] represent references given at the end of each chapter.

1.1.3 Criterion — Relative humidity and water vapor pressure. The operation of the H or HC system shall not cause the water vapor pressure in the dwelling occupied spaces to exceed 14mm Hg. Additionally, during heating, the operation of the H or HC system shall not cause the indoor relative humidity to exceed the appropriate values given in Figure 4 of Chapter 18 of the 1972 ASHRAE Handbook of Fundamentals[1].

Evaluation — Examination of climatic data, engineering review of drawings, specifications and calculations.

Commentary — The MPS do not provide for the control of dwelling water vapor pressure and relative humidity. The water vapor pressure specified (14.0mm of Hg.) is the upper limit for comfort conditions in ASHRAE Standard 55-74, "Thermal Environmental Conditions for Human Occupancy" [10].

Typical design procedures to gain acceptable water vapor pressure and relative humidity levels have been developed by ASHRAE [2] [3].

1.1.4 Criterion — Solar contribution. The average yearly contribution of solar energy to the operation of the H or HC systems shall be specified in the design and shall result in a reduction in the average annual consumption of conventional energy for the dwelling heating or cooling.

Evaluation — Engineering review of analytical methods, drawings, test data and calculations. An analytical model including the building heating and cooling loads, component performance and the climatic conditions shall be utilized to predict the percentage of average monthly and yearly total energy requirements to be provided by solar energy, operating energy, and auxiliary energy. In certain cases, experimental verification of system performance may be required. Theoretical determination of system performance generally requires empirical data defining the subsystem performance characteristics.

Commentary — Some examples of analytical methods and data presentation are shown in references [11] [12] [13] [14] [15] [16]. Sources of insolation data and data reduction methods are described in references [17] [18] [19] [20].

1.1.5 Criterion — Operational Impairment. The functional capability of the H or HC system shall not be impaired to a greater extent than conventional systems when system repairs or modifications are being made.

Evaluation — Engineering review of specifications and drawings.

Commentary — This criterion is intended to ensure that the shutdown for repair or modification of solar powered portions (e.g., the collector subsystem) of the H or HC system will not impair the function of the H or HC system for periods of time longer than those expected for conventional heating or cooling equipment.

The duplication of components such as blowers, controls and pumps is dependent upon the degree of integration of the auxiliary energy subsystem and the availability of replacement parts.

1.2 Requirement — DHW system/subsystem performance. The domestic hot water (DHW) system/subsystem shall be capable of collecting and converting radiant solar energy into thermal energy which shall be used in combination with storage, where provided, and auxiliary energy to supply an adequate amount of potable hot water at an acceptable temperature to meet the needs of the user.

1.2.1 Criterion — Water design temperature. The DHW system/subsystem shall meet the requirements established for draw and recovery specified in the MPS (Tables 6-15.2 and 6-15.3) [7] [8] at a tap temperature of 140°F.

Evaluation — Engineering review of plans, specifications and calculations.

Commentary — The amount of hot water required will vary with climate, dwelling type and number of occupants. Average family requirements of 50 gal. per day for domestic use and 75 gal. per day if an automatic cycle washer is used are common practice for estimating fuel costs for heating water[21]. Domestic hot water temperatures provided can vary from 105°F to 160°F but an average value 140°F should be used for calculating the energy requirements.

Typical procedures for determining domestic hot water requirements have been developed by ASHRAE[21].

1.2.2 Criterion — Storage design capacity. The DHW storage capacity shall not be less than the volume specified in the MPS [7] [8].

Evaluation — Review of drawings, specifications and calculations.

Commentary — Stratification in solar heated water containers may be different from that in conventional hot water storage tanks and should be considered in the design. High utilization of the solar collector is related to the storage component characteristics. Typical methods for calculating domestic hot water storage requirements are given by ASHRAE[21].

1.2.3 Criterion — Solar contribution. The average yearly contribution of solar energy to the operation of the DHW system/subsystem shall be specified in the design and shall result in a reduction in the average annual consumption of conventional energy for domestic hot water heating.

Evaluation — Engineering review and analysis of drawings, test data and calculations. An analytical model including at least the source water temperature, hot water requirements, DHW component performance, and the climatic conditions shall be utilized to predict the percentage of average monthly and yearly total energy requirements to be provided by solar energy, operating energy, and auxiliary energy from conventional energy sources.

Experimental verification of system performance shall be performed, where required. Theoretical determination of system performance generally requires empirical data defining the subassembly performance characteristics.

Commentary — Examples of analytical methods and data presentation are shown in the references [12] [13] [14] [21] [22] [23] [39].

1.2.4 Criterion <u>Operational Impairment</u>. The functional capability of the DHW system/subsystem shall not be impaired to a greater extent than conventional systems when system repairs or modifications are being made.

Evaluation Engineering review of specifications and drawings.

Commentary This criterion is intended to ensure that the shutdown for repair or modification of solar powered portions (e.g., the collector subsystem) of the DHW system/subsystem will not impair the function of the DHW system/subsystem for periods of time longer than those expected for conventional hot water equipment.

The duplication of components such as heat exchangers, controls and pumps is dependent upon the degree of integration of the auxiliary energy subsystem and the availability of replacement parts.

1.3 Requirement <u>Collector performance</u>. The solar collector shall absorb and convert incident solar energy into useful thermal energy. The collector shall be capable of dissipating thermal energy, where this function is included in the design.

1.3.1 Criterion <u>Collector efficiency</u>. The collector subsystem (including reflectors where applicable) shall be capable of absorbing and converting incident solar energy into useful thermal energy at its designed efficiency under operating conditions. For applications employing nocturnal radiation, the collector shall dissipate thermal energy at the design rate under design operating conditions.

Evaluation Engineering evaluation of drawings, analytical calculations and/or test data.

An analytical model, when used, shall include radiant, convective and conductive heat transfer, where appropriate.

The design collector thermal efficiency may be experimentally verified utilizing a full-scale test panel or a model test panel of sufficient size to have equivalent full-scale thermal characteristics.

It is intended that testing be performed only if performance data for the particular collector or one with similar materials and/or configuration is not available. Because of the influence of solar radiation characteristics, climatic conditions and system operating requirements on performance, experimental evaluations shall include heat transfer media flow rates and temperatures consistent with the geographic region and system conditions.

Commentary Some examples of analytical methods and data presentation are shown in the references [1] [12] [13] [14] [15] [16] [24] [25] [26] [27] [36] [37]. Descriptions of collector test techniques and representative test data are presented in references [13] [28] [29] [30] [31] to illustrate methodologies considered to be state-of-the-art. The use of material, fluid and insolation property data available in the open literature is encouraged.

1.4 Requirement — Thermal storage performance. When included in the design, the storage subsystem shall be capable of providing its rated output under design loads.

1.4.1 Criterion — Storage capacity and rate. The storage subsystem shall provide sufficient heat transfer rates and thermal energy capacity to absorb and store energy at the maximum design collection rate and, when fully charged, supply energy for its design time period with no solar energy or auxiliary energy input.

Evaluation — Engineering review of drawings, calculations and/or test data.

A thermal analysis of the storage subsystem shall be performed to determine the thermal energy storage capacity, heat losses, energy addition rate and energy extraction rate under operating conditions. For designs where adequate calculations are not possible these parameters shall be experimentally determined utilizing a full-scale test specimen or a model test specimen of sufficient size to have equivalent full-scale thermal characteristics.

Commentary — Descriptions of storage techniques and representative test data are presented in references [12][13][14][16][32][33][34] to illustrate methodologies considered to be state-of-the-art. The thermal capacity is a function of system dynamic characteristics and may be sized to include factors such as insolation level, collector area, thermal loads, energy loss, temperature gradients, material thermophysical properties and auxiliary energy type and amount.

1.5 Requirement — Habitability of occupied spaces. The presence of the system components shall not significantly affect the efficient operation of the H, HC or DHW systems or the habitability of the dwelling.

1.5.1 Criterion — Heat or humidity transfer effects. Heat or humidity transfer from the collector, thermal storage, piping or other elements shall not interfere with the efficient operation of the H, HC or DHW systems or cause loss of control of temperature, humidity or other comfort conditions.

Evaluation — Engineering review of drawings, specifications, calculations and test data. A thermal analysis including calculations of the heat transfer and condensation rates from all storage containers, piping and other thermally insulated components or test data on equivalent material and configurations shall be used.

Commentary — It is realized that some heat transfer from insulated piping and storage containers will occur within or under a building structure. Overheating and condensation can create adverse conditions for pumps, motors and controls. Design considerations are discussed in several references [2] [3] [7] [8] [9] [10] [35].

1.6 Requirement — Energy transport efficiency. The energy transport subsystem shall transfer the required thermal energy between the operating subsystems at or above the design efficiency under design full load conditions.

1.6.1 Criterion — Thermal losses and electrical power. Thermal losses and use of electrical power in the energy transport subsystem shall not exceed the operating design values.

Evaluation — Engineering review of drawings, specifications, calculations and test data.

Commentary — The losses in the distribution system influence the total system efficiency as well as operating electrical energy required for pumping. Variations in the thermal conductivity and specific heat of the heat transfer medium with temperature should be considered in the design. Design data and analytical procedures for thermal insulation and heat transfer in building systems are available in the literature [1] [2].

1.7 Requirement — Control. The control subsystem shall provide for the safe and efficient operation of the H, HC and DHW systems.

1.7.1 Criterion — Installation and maintenance. The control subsystem shall include such provision for manual bypass, adjustment, or over-ride of automatic controls as is required to facilitate installation, startup, shutdown and maintenance.

Evaluation — Review of drawings, specifications and operating procedures.

Commentary — Provision for manual controls may be needed during installation and start up to balance or adjust the system for proper operation. Other manual controls may be required for tests or maintenance after the system has been in operation or for seasonal shutdown.

1.7.2 Criterion — Manual adjustment. If manual controlled adjustments are required during normal operation of the H, HC and DHW system/subsystem, the control subsystem shall insure that:

a. The safety and durability of the H, HC and DHW systems and the dwellings in which they are installed are not compromised by failure to perform the manual adjustments for a reasonable period of time. The time period, as well as any contingent environmental conditions, shall be stipulated by the designer.

b. The control subsystem is designed for reasonable dwelling occupant convenience regardless of whether operating with solar energy, auxiliary energy or a combination of these energy sources.

Evaluation Review of drawings, specifications and operating procedures.

Commentary These provisions are not intended to restrict appropriate seasonal shut-down manual controls.

It is desirable that solar systems require no more operational supervision than conventional systems. However, demonstration systems may require various degrees of attention for periodic adjustments.

1.7.3 Criterion <u>Inhabited space temperature</u>. Each H and HC system shall be provided with at least one readily adjustable automatic control for the regulation of temperature in the living spaces. Each such control or combination of controls or sensors shall be capable of being set to control at least within the range from 55°F to 85°F.

Evaluation Review of drawings and specifications.

Commentary In certain multizone or multisystem applications, a priority control may be needed to avoid simultaneous heating and cooling of a common conditioned space. Controls presently used in conventional heating and cooling systems are capable of responding to a 1/2°F variation from the set point. Localized controls for building heating and cooling are discussed in reference [38].

1.7.4 Criterion <u>Hot water temperature</u>. The DHW system/subsystem shall be provided with a manually set, automatic control that provides effective regulation of the domestic water output temperature. The water temperature at the DHW storage tank shall be capable of being controlled within the range of 105°F to 160°F.

Evaluation Review of drawings and specifications.

Commentary The MPS requires that tap temperatures in one and two family dwellings for the elderly [7] and in all multifamily housing [8], must be below 140°F to prevent injury from scalding. The maximum temperature available from the tap is an important safety consideration which is addressed by most building codes and standards.

1.8 Requirement <u>Auxiliary energy</u>. The auxiliary energy subsystem shall be integrated into the H, HC and DHW systems to the extent necessary to automatically provide the designed heating, cooling and domestic hot water.

1.8.1 Criterion <u>Design loads</u>. The auxiliary energy subsystem shall be designed to meet the requirements for heating, cooling and domestic hot water specified in criteria 1.1.1, 1.1.2 and 1.2.1, respectively.

Evaluation Engineering review of plans, specifications, calculations and test methods.

Commentary The purpose of this criterion is to back up the H, HC and DHW systems used in the Demonstration Program with 100 percent operating capability when energy derived from solar radiation is not available. Design heating and cooling loads are discussed by ASHRAE [1] [2] [3] [38] and the MPS [7] [8] [9].

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*Available from American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 345 East 47th Street, New York, N.Y. 10017

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2.1 Requirement — System design conditions. The systems for heating (H) and combined heating and cooling (HC) and the domestic hot water (DHW) system/subsystem shall be capable of functioning at their designed flow rates, pressures and temperatures.

2.1.1 Criterion — Equipment capabilities. Pumps, fans, or other components shall be sized to move the heat transfer fluid through the collector, piping and/or ducts at design flow rates.

Evaluation — Review of drawings, specifications, historical performance, previous test data, and design calculations. Systems or applications that do not lend themselves to engineering analysis may require prototype tests to demonstrate compliance.

Commentary — In order to transfer heat through the system/subsystem, a number of different transfer approaches such as gravity circulation, combined forced and gravity circulation, or forced circulation may be used.

2.1.2 Criterion — Noise or erosion-corrosion. The piping or ducts and associated fittings shall be sized to carry the heat transfer fluid at design flow rates without excessive noise, as defined by HUD[1], or erosion-corrosion.

Evaluation — Review of drawings, specifications, historical performance, previous test data and design calculations.

Commentary — In order to prevent whistling noise in piping and cavitation noise in fittings and valves, it is recognized practice to limit velocities of transfer fluids to 8fps[2]. Lower velocities may be required depending on the limit set by the pipe manufacturer to prevent deterioration of their piping materials due to erosion-corrosion. It is common practice to limit flow velocities in small diameter copper tubing to 4fps when water having a pH value lower than 6.9 or softened water is used. A velocity of 4fps is commonly used as the upper limit for hot water piping with working temperatures above 150°F for copper tubing[2]. Some equipment designs may require higher flow velocities in order to inhibit scale formation. In air ducts, the velocities normally should not exceed recognized values, e.g., the values listed on U.L. labels.

2.1.3 Criterion — Operating conditions. Collectors, space heaters, water heaters, pumps, valves, regulating orifices, pressure regulators and similar components shall be capable of being operated over the pressure and temperature ranges anticipated in actual service without breakage, rupture, binding, galling, or significant loss in pressure that could impair their intended function.

Evaluation — Review of drawings, specifications, historical performance, previous test data and design calculations. Systems or components that do not lend themselves to engineering analysis shall be tested at the maximum and minimum service temperatures with anticipated fluid pressures. To show compliance with this criterion it is desirable that the design consist of components that are covered by recognized standards, where available, and are specified by the manufacturer to be suitable for the pressure, temperature, and flow application.

A list of recognized standards is given in the HUD Minimum Property Standards[3]. Available codes and standards are also listed in ASHRAE [4].

2.1.4 Criterion — Fluid flow in collectors. When an array of collectors is connected by manifolds, provision shall be incorporated in the manifolds and/or collectors to maintain the design flow rate of the heat transfer fluid through each collector.

Evaluation — Review of drawings, specifications, historical performance, previous test data, and design calculations or testing to determine that each collector will receive its design flow rate.

Commentary — Because of friction in the manifold, flow rates may be inadequate through collectors remote from the pump or other fluid supply source. This can result in inefficient collector operation. The provision of flow regulating valves is one means of correcting for this problem. Another method is the use of reversed supply and return headers for parallel arrays of collectors with graduated header sizes as the flow rate in the header changes. Useful design information is given in reference [5].

2.1.5 Criterion — Entrapped air. When liquid heat transfer fluids are used, the system shall provide suitable means for air removal.

Evaluation — Review of drawings and specifications.

Commentary — Trapped air in a piping system can impede the flow of liquids through piping, decrease pumping efficiency and otherwise reduce system efficiency. Possible icing up of exposed fittings is an important consideration.

2.1.6 Criterion — Thermal expansion of fluids. Adequate provisions for the thermal expansion of heat transfer fluids that would occur over the service temperature range shall be incorporated into the system designs.

Evaluation — Review of drawings, specifications and design calculations.

Commentary — Water expands about 4% in volume when heated from 40°F to 200°F. Other heat transfer fluids may have different coefficients of volume expansion. Means should be provided in the system design to contain this additional fluid volume without exceeding the operating pressure of the system or resulting in spillage.

2.1.7 Criterion — Pressure drops. Pressure drops shall not exceed the limits specified in the design.

Evaluation — Review of calculations, and detailed plan and elevation drawing layouts.

Commentary — Since the energy requirements of pumps and fans are a function of the system flow resistance, pressure drops should be kept as low as possible, commensurate with good design. The unnecessary use of fittings such as bends, tees, globe valves, reducers, or obstructions to flow should be avoided by careful arrangement of piping runs. Accepted practices for plumbing design are discussed in standard plumbing guides[6] [7].

2.1.8 Criterion — Condensate removal. Means shall be provided for adequate disposal of condensate from cooling equipment. Provisions shall be made to assure that condensate will overflow into a safe, appropriate drainage system.

Evaluation — Review of drawings and specifications.

Commentary — When the temperature of the cooling surface is at or below the dew-point temperature of the incoming air passing over the surface, water vapor from the incoming air will condense on the surface. The condensate will run off the surface to low points or collection points below the surface where it must be removed.

2.2 Requirement — Mechanical stresses. Mechanical stresses that arise within the system shall not cause damage or malfunction of the system or its components.

2.2.1 Criterion — Vibration stress levels. Vibrations in piping, ducts, instrumentation lines, and control devices shall be controlled to reduce stress levels below those that could cause fatigue and subsequent component damage.

Evaluation — Review of drawings, specifications, historical performance, and previous test data for adequate piping and equipment supports.

Commentary — Examples of possible vibration sources in piping are as follows:

a. Lengths of piping and connecting equipment that are resonant with pressure pulsation frequency.
b. Vibration resulting from motors, pumps, fans, and compressors which are not properly mounted.
c. Water hammer and quick closing valves.
d. Expansion and contraction of piping on hangers.
e. Wind pulsations on certain lengths and diameters of piping supported by loose hangers or supports.

2.2.2 Criterion — Vibration from moving parts. Pumps, fans and compressors or similar equipment shall be balanced and/or mounted in a manner that will avoid vibration that could cause damage or excessive noise as defined by HUD[1].

Evaluation — Review of drawings and specifications. Prototype inspection and testing if deemed necessary. The equipment supporting structure shall not have natural frequencies within $\pm$ 20 percent of the operating speeds. The equipment when mounted and placed in operation should not exceed a self-excited vibration velocity of 0.10 inches per second when measured with a vibration meter on the bearing caps of the machine in the vertical, horizontal, and axial directions or measured at the equipment mounting feet if the bearing caps are concealed[8].

2.2.3 Criterion — Water hammer. When a liquid is used as the transfer fluid and quick closing valves are employed in the design, the piping system shall be able to control or withstand potential induced "water hammer."

Evaluation — Review of drawings, specifications, and/or design calculations.

Commentary — Pressure rises resulting from water hammer may damage piping and equipment. It can be minimized by piping system design, or the use of water hammer arresters[9] [10].

2.2.4 Criterion — Vacuum relief protection.. Closed storage tanks and piping located at elevations above the system served shall be suitably protected against collapse by pressure if subjected to a vacuum. Such components shall be designed to withstand such pressures or have vacuum relief protection.

Evaluation — Review of drawings and specifications.

Commentary — Possible collapse of large diameter tanks and piping by atmospheric pressure is an important design consideration[11].

2.2.5 Criterion — Thermal changes. The system components and assemblies shall be designed to allow for the thermal contraction and expansion that would occur over the service temperature range.

Evaluation — Review of drawings, specifications and calculations.

Commentary — Piping and other components may experience changes in dimensions as a result of temperature changes. Such changes can result in excessive stresses within the piping, piping supports, structure, pumps, compressors, and solar collectors if means are not incorporated in the piping system design to allow for the thermal movement.

2.2.6 Criterion — Flexible joints. All systems employing heat transfer fluids shall be designed to be capable of accommodating flexing of plumbing and fittings.

Evaluation — Review of drawings and specifications.

2.3 Requirement — Leakage prevention. System assemblies containing heat transfer fluids shall not leak to an extent greater than that specified in the design when operated at the design conditions.

2.3.1 Criterion — Pressure test: nonpotable fluids. Those portions of the H, HC and DHW systems which contain heat transfer fluids (other than air) and are not directly connected to the potable water supply shall not leak when pressures of not less than 1-1/2 times their working pressure are imposed for a minimum of 15 minutes.

Evaluation — Review of specifications and testing. The test pressure shall be applied for a period of time necessary to inspect each joint for leakage. The pressure gage would be observed for this period to determine that a pressure drop has not occurred.

Commentary — Various building codes differ with regard to pressure tests. One plumbing code requires hydrostatic testing at the working pressure for water supply piping[12]. Another code requires hydrostatic testing at the working pressure or an air pressure test of not less than 50 psi for not less than 15 minutes[13]. A third code requires a hydrostatic test of not less than 25 psi above the working pressure [14]. However, plumbing codes do not give guidance concerning solar systems which can contain liquids other than water. In these cases, hydrostatic testing of the system at 1-1/2 times the maximum is considered to be appropriate[15]. "Dead-Weight" testers are frequently used to calibrate pressure gages[16].

2.3.2 Criterion — Pressure test: potable water. Those portions of the H, HC and DHW systems that are directly connected to the potable water supply system shall not leak when tested in accordance with the code having jurisdiction in the area where the system is used. In areas having no building code, a nationally recognized model code shall be used.

Evaluation — Review of drawings and specifications.

Commentary — See Commentary for 2.3.1

2.3.3 Criterion — Air transport systems. Duct systems shall be designed and installed in accordance with Section 615-4.3 of the HUD MPS[3].

Evaluation — Review of plans and specifications.

2.4	Requirement	Collector adjustments. The collector subsystem shall be capable of being located, oriented, and tilted as required by the design to capture sufficient solar energy to meet functional requirements.
2.4.1	Criterion	Orientation and tilt. The collector mount shall be capable of maintaining the design tilt and orientation.
	Evaluation	Review of drawings and specifications.
	Commentary	Collectors can either be fixed, require seasonal adjustment or be continuously movable. Detailed information concerning orientation and tilt is given in ASHRAE[17]. It is not the intent of this criterion that the collector necessarily be reoriented or tilted after initial installation.
2.4.2	Criterion	Mutual shadowing. Collectors shall be installed so that mutual shadowing does not exceed design limits.
	Evaluation	Review of drawings (site and system), specifications and calculations.
	Commentary	Data are available for calculating shading angles with respect to the time of day and year[18].
2.5	Requirement	Subsystem isolation. Shutdown of the subsystems in one dwelling unit shall not impair the distribution of energy to other dwelling units of the building.
2.5.1	Criterion	Shutdown in multifamily housing. The shutdown of the H, HC or DHW subsystems in one dwelling unit of a multifamily housing complex shall not interfere with the operation of the subsystems in other dwelling units.
	Evaluation	Review of drawings and specifications.
	Commentary	This is to permit the shutdown of equipment in an individual dwelling unit for repairs without impairing the operation of the equipment in other dwelling units that are connected to the same central system.
2.6	Requirement	Heat transfer fluid quality. Provision shall be made to maintain the quality of the heat transfer fluid at a level that does not impair its heat transfer function.

2.6.1 Criterion — Liquid quality. The system shall have means to prevent contamination by foreign substances that could impair the flow and quality of the heat transfer fluid beyond acceptable limits.

Evaluation — Review of piping drawings and specifications.

Commentary — The piping in some solar collectors and heat exchangers may have small cross sections in which blockage by dirt, scale, pieces of gasket material, pieces of packing, or other foreign matter in the heat transfer fluid could occur.

2.6.2 Criterion — Air quality. Duct and fan systems shall be protected against accumulation of deposits of dust or dirt that could reduce flow and efficiency.

Evaluation — Review of drawings and specifications for protection means.

Commentary — Accumulation of dust on fan blades, in collector heat transfer surfaces, and within the ducts will increase flow resistance, and decrease system efficiency.

2.6.3 Criterion — Fluid treatment. Suitable devices and procedures shall be provided to assure that the chemical composition of the heat transfer fluid is maintained at levels adequate to prevent unacceptable deposits on the heat transfer surfaces or corrosion of the surfaces with which the heat transfer fluid comes in contact.

Evaluation — Review of drawings and specifications.

Commentary — Problems can develop when fluids such as "hard" water are used.

2.6.4 Criterion — Freezing protection. Heat transfer liquids shall be prevented from freezing at the lowest ambient temperatures that will be encountered in actual use where such freezing would impair the function of the system.

Evaluation — Review of drawings and specifications.

Commentary — The purpose of this criterion is to insure that rupture or other damage to solar collectors and associated piping and equipment will not occur from expansion of water if it freezes. The intent of this criterion is not to restrict the designer to the use of antifreeze solutions.

2.7 Requirement — Piping supports. Pipe hangers, pipe trenches, and other supports shall carry the static and operational loads normally imposed without impairing system function.

2.7.1 Criterion — Applicable plumbing standards. Piping shall be installed in accordance with Section 615 of the MPS (4900.1 and 4910.1)[3] and Part C of the ANSI A119.1[19], where applicable.

Evaluation — Review of drawings, calculations and specifications.

Commentary — Both above-ground and underground piping and heat distribution installations are dealt with in the HUD MPS and other references [20] [21] [22] [23].

2.8 Requirement — Excessive pressure and temperature protection. The piping system and associated equipment shall be protected against rupture or leakage from excessive pressures and temperatures.

2.8.1 Criterion — Relief valves and vents. As required for protection of a particular system design, combination temperature and pressure relief valves, separate pressure relief valves, pressure reducing valves, and/or atmospheric vents shall be provided.

Evaluation — Review of drawings and specifications.

Commentary — This criterion is intended to prevent safety hazards resulting from inadequate pressure and temperature protection.

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*Available from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

†Available from American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 345 East 47th Street, New York, N.Y. 10017.

3.1 Requirement

Structural design basis. The structural design of the heating (H), combined heating and cooling (HC) and domestic hot water (DHW) systems including connections and supporting structural elements shall be in accordance with nationally recognized codes and standards and shall be based on loads anticipated during the service life of the systems.

3.1.1 Criterion

Applicable standards. The structural design and construction of H, HC and DHW systems including connections and structural supports thereof shall comply with the following provisions:

Conventional elements* shall comply with the provisions of the HUD Minimum Property Standards (MPS)[1] for single family and multifamily housing or ANSI A119.1[4], in the case of mobile homes, and such additional criteria as specified in this chapter. Non-conventional elements** shall comply with all the criteria stipulated in this chapter.

Evaluation

Review of drawings, specifications and structural calculations.

Commentary

In addition to complying with the design and construction provisions of the MPS or ANSI A119.1 (for mobile homes), conventional elements and connections are required to comply with Criteria 3.1.2 (Service loads), 3.2.2 (Ice loads), 3.2.3 (Vehicular loads), 3.5.1 (Design provisions - cutting of structural elements), 3.7.1 (Hail size and loading), and 3.9.1 (Design provisions - ponding conditions).

3.1.2 Criterion

Service loads. The following loads shall be used in the structural design of conventional and non-conventional elements and connections of H, HC and DHW systems:

1. Dead loads (D) shall be the "Design Dead Loads" stipulated in Section 601-3 of the MPS.

2. Live loads (L) shall be all applicable "Design Live Loads" stipulated in Section 601-4 and "Snow Loads" stipulated in Section 601-5 of the MPS.

3. Wind loads (W) shall be "Wind Loads" stipulated in Section 601-6 of the MPS. In all cases consideration of local wind conditions shall be assured by compliance with Section 6.3.3 of ANSI A58.1[2].

4. Earthquake loads (E) shall be those stipulated in Section 601-9 of the MPS which references the provisions of the Uniform Building Code (UBC) [3]. For non-conventional system components and connections, the value of "Cp" used in the UBC shall be taken as 2.0.

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* Conventional elements and connections (as used in this chapter) are defined as those elements and connections for which the design and construction provisions of the Minimum Property Standards (MPS) or ANSI A119.1 are applicable.

** Non-conventional elements and connections are defined as those elements and connections for which the design and construction provisions of MPS or ANSI A119.1 are not applicable.

5. Constraint loads caused by the environment, normal functioning of the system and time-dependent changes within the materials of the system shall be taken as the most severe likely to be encountered during the service life.

6. Constraint loads induced by differential foundation settlement shall be taken as those corresponding to a differential foundation settlement of the magnitude stated under Criterion 3.8.1.

7. Ice loads (I) shall be taken as those produced by the accumulation of ice on surfaces exposed to the natural environment. The thickness of ice shall be determined in accordance with Criterion 3.2.2.

8. Hail loads (H) shall be taken as those produced by the impact of hail on surfaces exposed to the natural environment. Hail particle size and kinetic energy at impact shall be determined in accordance with Criterion 3.7.1.

9. Vehicular loads on below grade installations shall be determined in accordance with Criterion 3.2.3.

Evaluation

For experimental or analytical evaluation of structural response, the selection of system components shall be done in a manner representing the least margin of safety to the system but consistent with its interaction with structural systems to which they are attached. Test loads applied to the system components shall result in the most critical conditions encountered in service. Additional eccentricities of loading caused by drift due to lateral loads and anticipated differential foundation settlements shall be provided for in tests of supporting structural elements of the system. The effects of service history caused by fatigue, sustained load, temperature, moisture, ultraviolet light or other environmental factors, shall be provided for in tests.

Commentary

The intent of the criterion is to state the required reliability of performance and, therefore, the specified loads should have a defined probability of occurrence.

The assumption is made (with the exception of wind and snow loads, which are based on statistical analysis) that the MPS "design loads" are loads anticipated during the service life of the system.

The minimum uniformly distributed live load on relatively flat horizontal and inclined surfaces of the system is taken in accordance with roof loads prescribed by MPS. Snow load is based on ANSI A58.1 and is treated as live load in lieu of the MPS roof load if it produces a more severe loading condition. This is consistent with MPS which uses ANSI A58.1 by reference.

Earthquake loads are determined by the applicable provisions of the Uniform Building Code. It is recognized that for cases involving new material applications it may be difficult to select the appropriate C_p factor. The prescribed C_p value intended for use with non-conventional elements and connections is consistent with the values specified in UBC for connections of exterior panels.

3.2 Requirement — Failure loads and load capacity. The structural elements and connections of the H, HC and DHW systems shall not fail under ultimate loads expected during the service life of the system.

3.2.1 Criterion — Ultimate load combinations. Non-conventional elements and connections shall comply with this criterion. (Conventional elements and connections are deemed to satisfy this criterion.)

Structural components, connections and supporting elements shall be designed for the following ultimate load combinations:

(1) 1.4 D + 1.7 L
(2) 0.9 D + 1.7 W
(3) 0.9 D + 1.45 E
(4) 1.1 D + 1.3 L + 1.7 W
(5) 1.1 D + 1.3 L + 1.45 E

where the multipliers are load factors and the letters are the service loads defined in Criterion 3.1.2.

Evaluation — Review of structural calculations, specifications and drawings.

Commentary — The intent of the criterion (along with Criterion 3.2.4) is to provide a minimum level of safety against loading situations which have a suitably low probability of occurrence during the service life. The load factors represent present-day design practice for building structures and are similar to the load factors used in ACI 318[5]. These factors will produce ultimate loads comparable to those presently used in the design of steel structures. Adoption of similar levels of performance requirements for the H, HC and DHW systems will also permit the designer to explore the potential use of system components as structural elements for purposes of providing enclosure or diaphragm rigidity to the supporting structure in addition to their primary heating and/or cooling function.

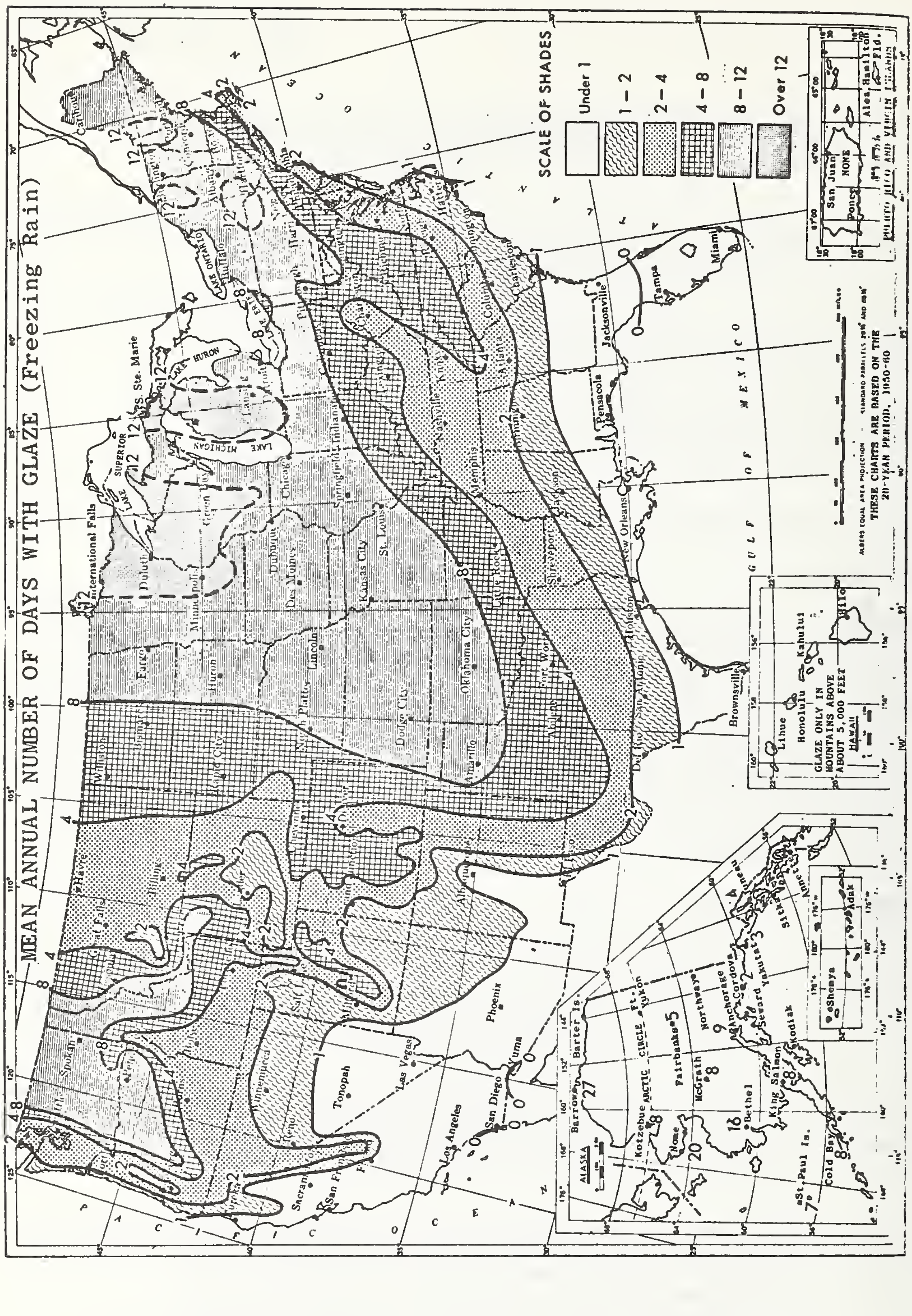
3.2.2 Criterion — Ice Loads.

(a) Above-ground installations of conventional elements for which ultimate design provisions apply, and of all non-conventional elements, including connections and structural supports thereof, shall comply with Criterion 3.2.1 for load combinations (1) and (4) in which live load (L) shall be taken as that produced by the accumulation of ice on all surfaces exposed to the natural environment.

(b) Above-ground installations of conventional elements for which working stress design provisions apply, including connections and structural supports thereof, shall comply with Criterion 3.2.2(a) with the following modification: load factors in load combinations (1) and (4) of Criterion 3.2.1 shall be taken as 1.0.

The radial thickness of ice around the circumference of exposed wires, pipes, and structural members shall be based on the annual frequency of occurrence of glaze shown in Figure 3.2.2 (see reference [6]) and shall be computed as follows:

Mean annual number of days with glaze	under 1	1-4	4-8	over 8
Thickness of ice (inches)	0	1/2	3/4	1.0



MEAN ANNUAL NUMBER OF DAYS WITH GLAZE (Freezing Rain)
SCALE OF SHADES
Under 1
1 – 2
2 – 4
4 – 8
8 – 12
Over 12
GLAZE ONLY IN MOUNTAINS ABOVE ABOUT 5,000 FEET
HAWAII
ALASKA
PUERTO RICO AND VIRGIN ISLANDS
NONE
THESE CHARTS ARE BASED ON THE 20-YEAR PERIOD, 1940-60
GULF OF MEXICO
PACIFIC OCEAN
ATLANTIC OCEAN

FIGURE 3.2.2

Evaluation — Review of structural calculations.

Commentary — The intent of this criterion is to account for the effect of ice loads primarily on wires, pipes and other similar components which are exposed to the natural environment, in recognition of the fact that ice storms have been particularly detrimental to such components in the past.

The map of Figure 3.2.2 with documented information of the accumulation of ice recorded for major ice storms [6] and ice loads considered in the design of steel transmission pole structures [7] have been utilized to relate thickness of ice to frequency of occurrence of such storms. This assumption is made in view of a lack of statistical data on accumulation of ice and should result in a generally conservative practice even though it is recognized that thickness of ice cannot be solely expressed in terms of rate of occurrence.

3.2.3 Criterion — Vehicular Loads.

(a) Below grade installation of conventional elements for which ultimate design provisions apply, and of all non-conventional elements, including connections and structural supports thereof, subjected to heavy vehicular traffic shall not fail under load combination (1) of Criterion 3.2.1 where dead load (D) and live load (L) are calculated in accordance with the AASHO provisions on distribution of loads through earth fills [8]. For sites other than those specifically designed for general public and commercial vehicular traffic, the wheel loads shall be taken as those induced by an AASHO H20-44 truck without impact.

(b) Conventional elements for which working stress design provisions apply shall comply with Criterion 3.2.3(a) with the following modification: load factors in load combinations (1) and (4) of Criterion 3.2.1 shall be taken as 1.0.

Evaluation — Analysis using the principles of soil mechanics for specified conditions of bedding and backfill.

Commentary — The criterion specifies the level of vehicular traffic for which buried components should be designed in cases where heavy vehicular traffic is anticipated to occur in service for purposes of access. The H20-44 truck is considered to be representative of load levels associated with heavy vehicles such as trucks for repair, maintenance, moving, and delivery of fuel.

3.2.4 Criterion

Load Capacity. Non-conventional elements and connections shall comply with this criterion. (Conventional elements are deemed to satisfy this criterion.)

The load capacity, R, of the system or a portion thereof shall exceed the required ultimate load, U, in Criterion 3.2.1 and shall be derived from the mean load capacity R_m:

$$U \leq R = R_m \, \emptyset \, c_u$$

where:

$\emptyset$ = variability factor which shall be such that approximately 95% of the system or portions thereof exceed $R_m\emptyset$ in resistance. For normal distribution of resistance, $\emptyset = 1 - 1.65v$.

v = coefficient of variation of resistance with respect to R_m.

c_u = coefficient for ductility = $(\mu + 7)/12$, but not more than 1.0 for loadings not including earthquake, and equal to 1.0 for loadings including earthquake.

μ = ductility factor for loading condition U, as defined under Evaluation below.

Evaluation

Where adequate existing test data on the various material properties comprising the system are available, evaluation will be performed using engineering analysis. Where adequate test data is unavailable, system elements and subassemblies will be evaluated in the laboratory using simulated static load levels consistent with the specified load combinations.

The ductility factor will be evaluated as follows: For an ideal elasto-plastic (elastic-perfectly plastic) resistance function (plot of applied load as ordinate and deflection as abscissa), the ductility factor is defined as the ratio of ultimate deflection to yield deflection ($\mu = d_u / d_{ye}$). For an actual (nonlinear) function, the ductility factor shall be computed from an "effective" function (Fig. 3.2.4). The effective function consists of 2 straight lines. The first line is drawn through the origin and a point on the actual function at which the resistance is 60 percent of its maximum load value (P_u). The second line is a horizontal line ending at the ultimate deflection (d_u), which shall not exceed that where the resistance function falls below 95 percent of its maximum load value. The horizontal line is located so that the area under the 2 lines forming the effective function is equal to the area under the actual function up to the point of ultimate deflection. Effective yield deflection (d_{ye}) shall be taken as the deflection at the point of intersection of the 2 lines, which is at a resistance level termed "effective yield resistance." The ductility factor is based on the effective resistance function: $\mu = d_u/d_{ye}$.

Commentary

The intent of this criterion (along with Criterion 3.2.1) is to provide a minimum level of safety against loading situations which have a suitably low probability of occurrence during service life.

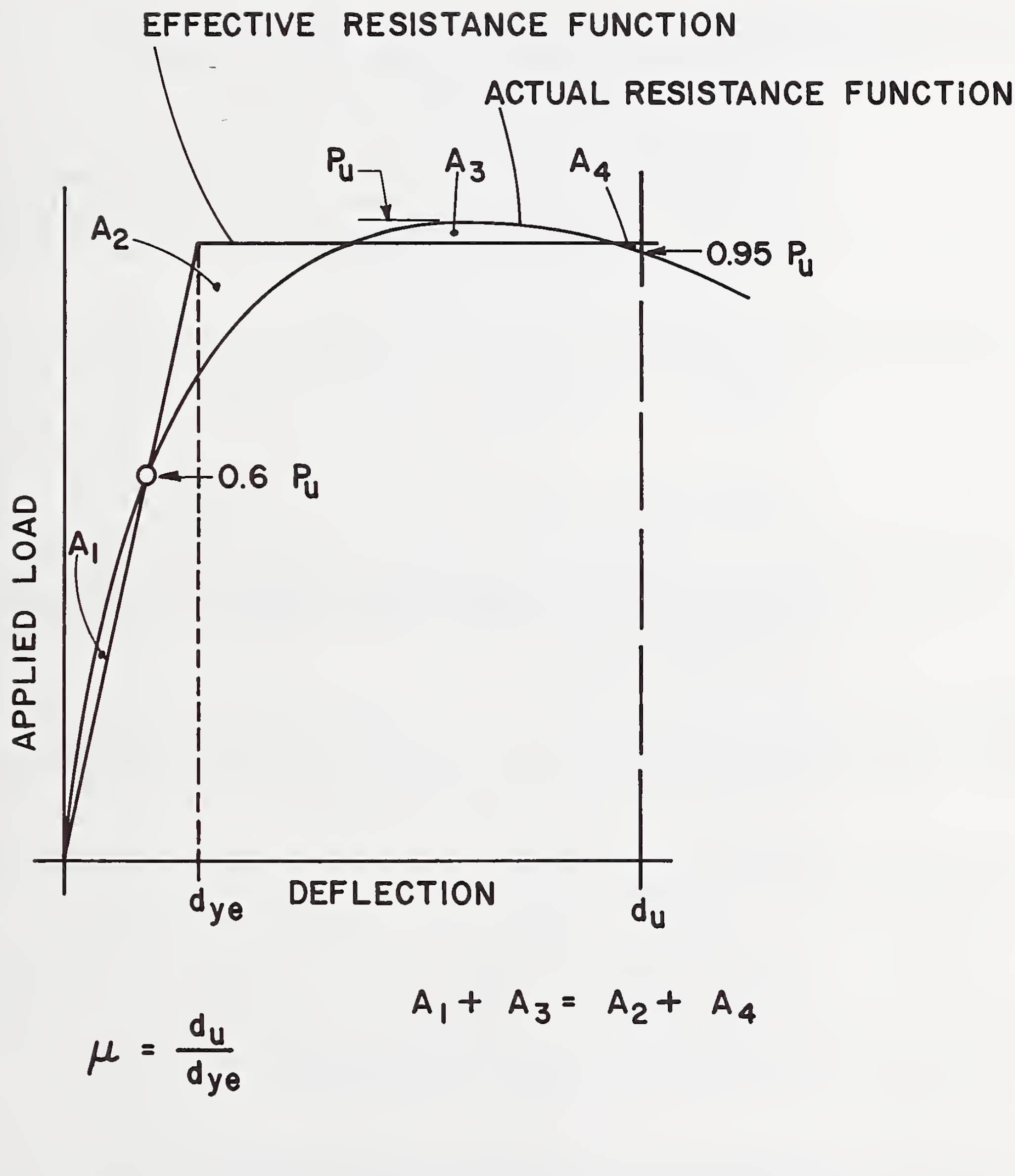


FIG. 3.2.4. DETERMINATION OF THE DUCTILITY FACTOR

3.3 Requirement — Damage control. The structural elements and connections of H, HC and DHW systems shall be designed to withstand service loads without damage of unacceptable magnitude.

3.3.1 Criterion — Resistance to damage. Non-conventional elements and connections shall comply with this criterion. (Conventional elements and connections are deemed to satisfy this criterion.)

Under the effect of deflections caused by loading combinations of (1), (2) and (4) of Criterion 3.2.1, with load factors of 1.0, in addition to the anticipated creep deflections, the system as a whole or any component, connection or support thereof, shall not suffer permanent damage which would require replacement or repair, or which would impair its intended function during its service life.

Evaluation — Evaluation of documented data for design, tests, and installation. Evaluation and/or testing of components and elements where deemed essential. Determination of compliance with generally accepted standards and engineering and trade practices, where applicable.

The criterion is deemed satisfied if it can be demonstrated that deflections caused by the specified load combinations can be accommodated by suitable details or adequate flexibility.

Commentary — The intent of this criterion is to provide for the proper functioning of the system under service loading conditions without breakdown or permanent impairment beyond levels comparable to conventional heating and cooling systems.

3.3.2 Criterion — Glazing design. The selection and installation of glazing materials shall be in accordance with sections 508 and 608 of the MPS and Part B of ANSI A119.1, where applicable.

Evaluation — Review of drawings and specifications. Testing to show compliance, where necessary.

Commentary — This criterion is intended to deal with potential hazards that could occur when frangible materials such as glass are used in applications such as collector cover plates.

3.4 Requirement — Cyclic loads. The structural elements and connections of H, HC and DHW systems shall not fail under the application of cyclic loads expected during the service life.

3.4.1 Criterion

Deflection limitations. Non-conventional elements and connections shall comply with this criterion. (Conventional elements and connections are deemed to satisfy this criterion.)

Structural components, connections and supporting elements shall be capable of resisting the following repeated loads without failure and without a residual deflection in excess of 25 percent of the maximum deflection measured in the first cycle of load application:

(1) 100 cycles from 1.0 D to 1.0 D + 0.5 L
(2) 1000 cycles from 1.0 D to 1.0 D + 0.5 W

Evaluation

Physical simulation and testing or analysis based on available test data.

The cyclic loading (1) and (2) shall be assumed to be applied after reducing system slack by the prior application of one preloading cycle of the following loads:

for (1) from (1D) to (1D + 1L)

for (2) from (1D) to (1D + 1W)

Cyclic loading shall commence only after deflection recovery from the preloading cycle is substantially complete. The residual deflection shall be taken as the difference between the deflection measured 24 hours after removal of the superimposed cyclic load and the residual deflection, if any, not recovered from the preloading cycle.

Commentary

Even though the service load history cannot be simulated the imposition of the stipulated cyclic loads is intended as a conservative representation of service conditions. The residual deflection limitation assures preservation of structural integrity under cyclic loading.

3.5 Requirement

Cutting of structural elements. Cutting of structural elements for the installation of H, HC and DHW system components shall not reduce the required load capacity of structural elements.

3.5.1 Criterion

Design provisions. The effect on the size, shape or engineering properties of a load-bearing element resulting from holes, copes, notches, etc., shall be determined to insure that required safety margins against failure have been maintained.

Evaluation

Review and evaluation of drawings, specifications, structural calculations. Analysis of the altered structural configuration to ascertain that the required safety margins are not reduced.

Commentary

Arbitrary drilling, punching, or other reductions in size or cross section of supporting structural elements in order to provide passage of system components can seriously reduce structural capacity of the system.

3.6 Requirement — Creep and residual deflection. The load capacity of structural connections and elements supporting the H, HC and DHW system components shall not be impaired by the effect of creep and residual deflections.

3.6.1 Criterion — Deflection limitations. Non-conventional elements and connections shall comply with this criterion. (Conventional elements and connections are deemed to satisfy this criterion.)

(a) Load capacity shall be evaluated taking into consideration the effect of creep and residual deflections. The deflection of structural elements supporting the system components shall not exceed the following limitations:

With the full dead load (1.0 D) in place, the maximum deflection due to a superimposed load of 0.2D + 1.5L, sustained for 24 hours shall not exceed

$$\frac{1.25s}{180} \cdot \frac{0.2D + 1.5L}{L}$$

where s = span length.

(b) The maximum residual deflection measured not more than 24 hours after removal of the superimposed load specified in (a) shall not exceed

$$\frac{0.25s}{180}$$

Evaluation — Analysis and/or physical simulation including tests on prototype supporting structures. Deflections shall be measured in a direction normal to the span.

One preloading cycle is permitted, provided that loading in the actual test does not commence before deflection recovery from the preloading cycle is substantially complete.

Commentary — Loads lower than required ultimate loads should not cause large, irrecoverable deformations. It is not unreasonable to require non-conventional structures to resist the stipulated superimposed loads without resulting in significant residual deformations. The limitation in part (a) implies deflection limitation of s/180 under service live load (1.0 L) with an additional 25 percent allowance for creep.

Part (b) requires 75 percent elastic recovery of deflection. This guards against significant residual deflection increases in each cycle of loading that may lead to incremental collapse.

3.7 Requirement — Hail resistance. H, HC and DHW system components and supporting structural elements exposed to the natural environment shall be capable of resisting impact by hail without unacceptable damage.

3.7.1 Criterion

Hail size and loading. System components and supporting structural elements that will be exposed to the natural environment in service shall be designed to resist, without excessive damage or major impairment of the functioning of the system, the perpendicular impact of falling hail having a particle diameter (in inches) equal to 0.3d where d is the mean annual number of days with hail determined on the basis of the hail map shown in Figure 3.7.1 [6].

Evaluation

Evaluation will be based on analysis using known structural information on the physical characteristics of the system components or on physical simulation and testing using the NBS hail resistance test described in the NBS Building Science Series 23[9]. In the absence of physical test data, the portion of the kinetic energy dissipated by system components shall be taken as 50 percent of the kinetic energy at impact corresponding to the resultant velocity specified in Table 3.7.1 (reproduced from Ref. [10]) for the predetermined hail size.

In cases where protective measures are provided to prevent impact of hail on system components, such as the use of screens or deflectors, these protective measures shall be included in the test specimens.

Commentary

It is not the intent of this criterion to prevent punching or local cracking of nonstructural elements such as glass cover plates of collector panels under hail impact, but rather to control damage by keeping it at a level which would not create a major curtailment in the functioning of the system, premature failure or hazards created by excessive shattering of glazed elements.

The correlation of hail size with mean annual number of days with hail is based on studies on the probability of exceedance of a given particle size as a function of frequency of occurrence of hail, a twenty year recurrence interval reflecting the life expectancy of the system and observations of statistical data [11] indicating that a representative hailstorm area is generally one order of magnitude smaller than the regions for which statistical information is compiled.

3.8 Requirement

Constraint loads. The structural elements and connections of H, HC and DHW systems shall comply with Criterion 3.2.1 while simultaneously subjected to constraint loads expected during the service life.

3.8.1 Criterion

Foundation settlement; contraction and expansion. Non-conventional elements and connections shall comply with this criterion. (Conventional elements and connections are deemed to satisfy this criterion.)

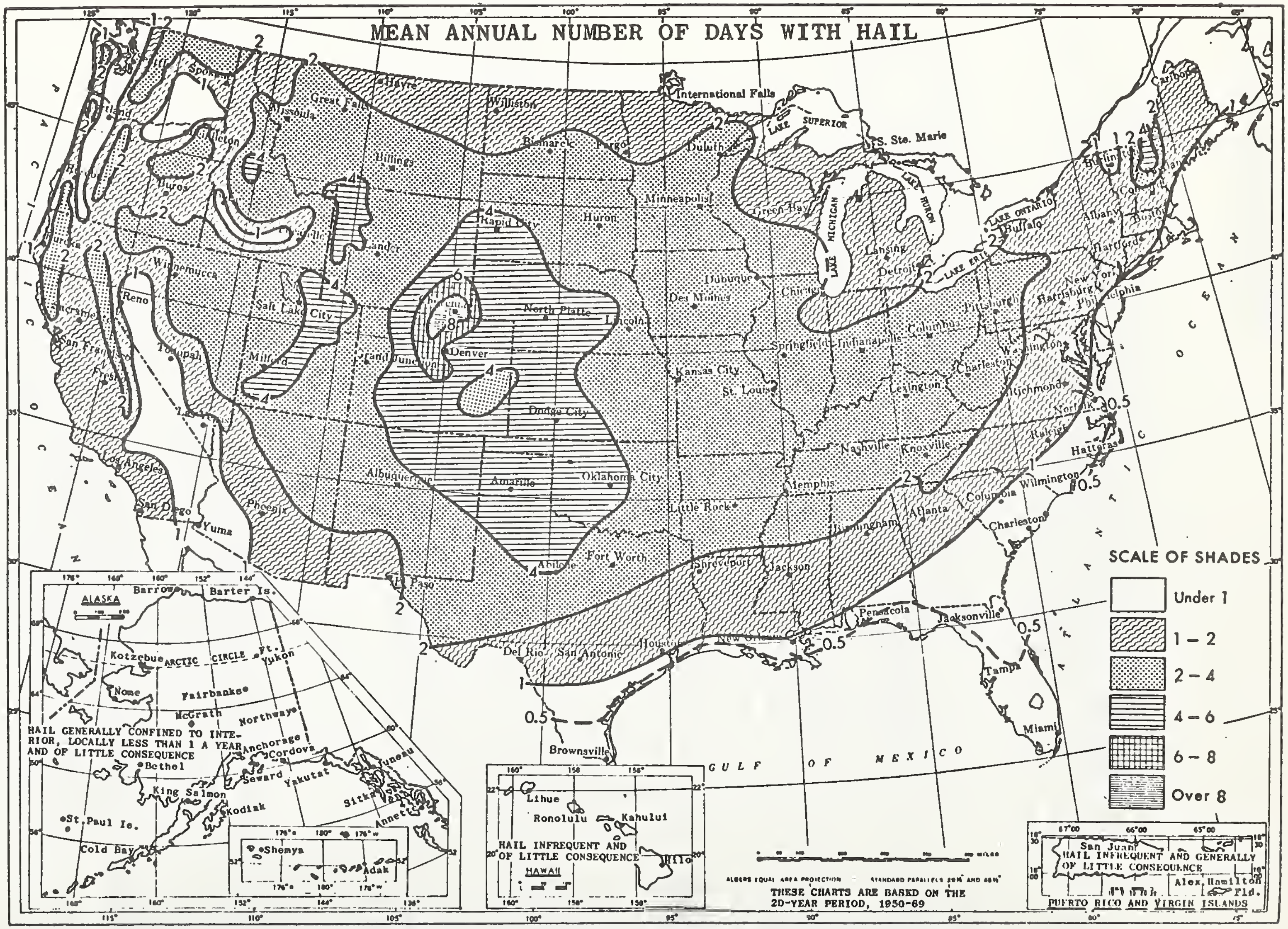

MEAN ANNUAL NUMBER OF DAYS WITH HAIL
SCALE OF SHADES
Under 1
1 – 2
2 – 4
4 – 6
6 – 8
Over 8
HAIL GENERALLY CONFINED TO INTERIOR, LOCALLY LESS THAN 1 A YEAR AND OF LITTLE CONSEQUENCE
ALASKA
HAIL INFREQUENT AND OF LITTLE CONSEQUENCE
HAWAII
HAIL INFREQUENT AND GENERALLY OF LITTLE CONSEQUENCE
PUERTO RICO AND VIRGIN ISLANDS
THESE CHARTS ARE BASED ON THE 20-YEAR PERIOD, 1950-69
GULF OF MEXICO

FIGURE 3.7.1

TABLE 3.7.1

Values of weight, terminal velocity, resultant velocity and kinetic energy computed for smooth ice spheres.

Diameter in	Weight gm	lb	Terminal Velocity ft/sec	Resultant Velocity ft/sec	Kinetic Energy 1/ ft-lb	
1/2	0.98	0.002	51	83	0.09	0.24
3/4	3.30	0.007	62	91	0.44	0.94
1	7.85	0.017	73	98	1.43	2.58
1 1/4	15.33	0.034	82	105	3.53	5.79
1 1/2	26.50	0.058	90	112	7.35	11.38
1 3/4	42.08	0.093	97	117	13.56	19.73
2	62.81	0.138	105	124	23.71	33.07
2 1/4	89.43	0.197	111	129	37.73	50.96
2 1/2	122.67	0.270	117	134	57.48	75.39
2 3/4	163.28	0.360	124	140	85.95	109.57
3	211.98	0.467	130	146	122.66	154.71

1/ First value corresponds to the terminal velocity and the second value corresponds to the resultant velocity.

System components, connections and supporting elements shall comply with Criterion 3.2.1 while simultaneously subjected to the following constraint conditions:

1. A differential foundation settlement of 2 inches in any horizontal distance of 50 feet except that in cases where the foundation at a particular site is specifically designed to control differential settlements, the constraint conditions should be those consistent with the specified design. Uplift forces caused by a swelling of expansive soils shall be calculated assuming a level of 0.9D for gravity loads.

2. Constraint loads arising from thermal expansion and contraction of system components and structural elements or from time-dependent changes within the material.

Evaluation — Analysis and/or physical simulation.

Commentary — Soil-structure interaction is usually a design function since constraint loads are dependent on the characteristics of the soil as well as the effects of structural framing. Due to economic considerations in foundation design, the assumption is usually made that the superstructure is capable of accommodating a reasonable amount of differential settlement. The requirement in part (1) is consistent with observed performance of conventionally designed foundations and represents the threshold at which structural damage occurs. This criterion is relaxed when special precautions are used in foundation design to control differential settlements.

The requirements in part (2) of the criterion account for other types of constraint loads such as those introduced by thermal expansion and contraction of system components or creep and shrinkage in supporting structural elements.

3.9 Requirement — Ponding conditions. Horizontal surfaces of the H, HC and DHW systems shall be designed in a manner that will assure stability in service under ponding conditions.

3.9.1 Criterion — Design provisions. Horizontal surfaces exposed to the exterior environment shall be designed to have either sufficient stiffness to prevent failure as a result of ponding caused by the accumulation of water or shall be provided with sufficient slope to permit free drainage or adequate individual drains to prevent the accumulation of water.

Evaluation — Analysis based on documented strength and stiffness properties or physical simulation and testing.

Commentary — Ponding is defined as the retention of water due to the deflection of horizontal surfaces. The lack of sufficient vertical stiffness causes the surface to continuously deflect and accumulate additional water until collapse occurs.

References

1. HUD Minimum Property Standards, One and Two Family Dwellings (No. 4900.1), U.S. Department of Housing and Urban Development, Washington, D.C. (1973, revised 1974)* and HUD Minimum Property Standards, Multifamily Housing (No. 4910.1), U.S. Department of Housing and Urban Development, Washington, D.C. (1973).*

2. Building Code Requirements for Minimum Design Loads in Buildings and Other Structures, ANSI A58.1-1972, American National Standards Institute, New York, N.Y. (1972).

3. Uniform Building Code, International Conference of Building Officials, Whittier, Cal. (1973).

4. Standard for Mobile Homes, ANSI A119.1-1974, American National Standards Institute, New York, N.Y. (1974).

5. Building Code Requirements for Reinforced Concrete, ACI318-71, American Concrete Institute, Detroit, Mich. (1971).

6. Baldwin, J.L., Climates of the United States, U.S. Department of Commerce, Washington, D.C. (1973).*

7. "Design of Steel Transmission Pole Structures," Task Committee on Steel Transmission Poles of the Committee on Analysis and Design of Structures, Journal of the Structural Division, American Society of Civil Engineers, New York, N.Y. (December 1974).

8. Standard Specifications for Highway Bridges, American Association of State Highway Officials (AASHO), Washington, D.C. (1973).

9. Greenfield, H., Hail Resistance of Roofing Products, Building Science Series 23, National Bureau of Standards, Washington, D.C. (August 1969).*

10. Mathey, R.G., Hail Resistance Tests of Aluminum Skin Honeycomb Panels for the Relocatable Lewis Building, Phase II, NBS Report 10 193, National Bureau of Standards, Washington, D.C. (1970).

11. Storm Data, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service (monthly periodical).

*Available from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

4.1 Requirement — Plumbing and electrical installation. The design and installation of the systems for heating (H), combined heating and cooling (HC) and the domestic hot water (DHW) system/subsystem and their components shall be in accordance with nationally recognized plumbing and electrical codes and standards for health and safety, where applicable.

4.1.1 Criterion — Plumbing codes and standards. Plumbing materials and equipment and their installation shall be in accordance with Sections 515 and 615 of the MPS (4900.1 and 4910.1)[1] and Part C of ANSI A119.1[2], where applicable.

Evaluation — Review of drawings and specifications. Testing to show compliance, where necessary.

Commentary — Suitable standards are available for conventional equipment. Unique innovative installations may require special consideration.

4.1.2 Criterion — Electrical codes and standards. Electrical materials and equipment and their installation shall be in accordance with Sections 516 and 616 of the MPS (4900.1 and 4910.1)[1] and Part E of ANSI A119.1[2], where applicable.

Evaluation — Review of drawings and specifications. Testing to show compliance, where necessary.

Commentary — Suitable standards are available for conventional equipment. Unique installations may require special consideration.

4.2 Requirement — Fail-safe controls. The H, HC and DHW systems shall be fail-safe in the event of damage to system components or a power failure.

4.2.1 Criterion

System failure prevention. The control subsystem shall be designed so that in the event of a power failure, or a failure of any of the components in the subsystem, the temperatures and/or pressures developed in the H, HC and DHW systems will not be damaging to any of the components of the systems, and the building, or present a danger to the occupants. The safety devices shall meet the requirements of Section 515-6.4 of the MPS (4900.1 and 4910.1)[1].

Evaluation

Review of drawings, specifications and design calculations.

Perform test of fail-safe control installation for all probable failure events.

Commentary

The excessive pressures and temperatures that can build up in collectors under "no flow" conditions are an important consideration. Consideration should be given to the thermal shock which could occur when cool heat transfer fluids are introduced into collectors which have been exposed to solar radiation under "no flow" conditions.

4.2.2 Criterion

Automatic pressure relief valves. Adequately sized and responsive automatic pressure relief valves shall be provided in those parts of the energy transport subsystem containing pressurized fluids. Automatic pressure relief valves shall be set to open at not less than 25 percent in excess of working pressure and at not more than maximum pressure for which the subsystem is designed.

Evaluation

Review of plans and specifications, and/or determination that methods, devices, and materials to be used are approved by a recognized testing and evaluation agency as being suitable for the proposed use.

4.3 Requirement

Fire safety. The design and installation of the H, HC and DHW systems and their components shall provide a minimum level of fire safety consistant with applicable codes and standards.

4.3.1 Criterion

Applicable fire standards. Assemblies and the materials used in the H, HC and DHW systems shall comply with nationally recognized codes and standards for fire safety, where applicable.

Evaluation

Review of drawings and specifications for conformance with the MPS, ANSI A119.1, and applicable sections of NFPA 89M[4], NFPA 90A and 90B[5], NFPA 211[6], NFPA 54[7], NFPA 31[8], ASTM E 108[9] and the National Electric Code [10]. Testing to show compliance, when necessary. Potential heat, rate of heat release, ease of ignition, and smoke generation will be considered in assessing potential fire hazards.

Commentary It is the intent of this criterion to (1) prevent the use of materials, equipment and fluids which present a fire hazard significantly greater than that of conventional systems,(2) to provide proper clearances and venting of heat build-up for those system components that operate at elevated temperatures, and (3) to give consideration to the combustibility of materials adjacent to high temperature components in determining the clearances that are required.

4.3.2 Criterion <u>Penetrations through fire-rated assemblies</u>. Penetrations through fire rated walls, partitions, floors, roofs, etc. shall not reduce the fire resistance below the levels specified in Section 405 of the MPS (4900.1 and 4910.1)[1], where applicable.

Evaluation Review of drawings and specifications. Testing to show compliance, where necessary.

Commentary It is the intent of this criterion (1) to prevent the passage of system components through fire-rated assemblies from adversely affecting the fire endurance rating of the assembly, and (2) to ensure that proper techniques are employed in constructing these components so that adequate protection can be provided.

4.4 Requirement <u>Toxic and flammable fluids</u>. Heat transfer fluids which require special handling because of toxicity and/or flammability shall not be used unless the systems in which they are used are designed to avoid exposing the occupants of dwellings to unreasonable hazards.

4.4.1 Criterion <u>Provision of catch basins</u>. Adequately sized and protected catch basins shall be provided, when liquids requiring special handling are used, to collect and store the overflow from pressure relief valves, liquids drained from the system when it is being serviced, potential leakage, and accidental drainage.

Evaluation Review of drawings and specifications.

Commentary The leakage of toxic fluids into the ground could contaminate the ground water.

4.4.2 Criterion <u>Detection of toxic and flammable fluids</u>. If heat transfer fluids that require special handling are used, means shall be provided for the detection of leaks and the warning of occupants when leaks occur.

Evaluation Review of drawings and specifications. Testing of detection and warning system(s).

Commentary It is common practice to relate toxicity and flammability ratings to the level of hazard created at ambient temperatures. Heat transfer

fluids which do not present a hazard at ambient temperatures may be hazardous at the temperatures developed in the system.

4.5 Requirement

Safety under emergency conditions. In the event of emergencies, the H, HC and DHW systems shall not unduly hinder the movement of occupants of the building or emergency personnel. Life safety hazards which could occur as a result of failures of the above systems shall not be greater than those imposed by conventional systems.

4.5.1 Criterion

Emergency egress and access. The design and installation of the H, HC and DHW systems shall not impair the emergency movement of occupants of the building or emergency personnel to an extent greater than that allowed by Sections 402 and 405 of the MPS (4900.1 and 4910.1)[1] and NFPA 101[3], where applicable.

Evaluation

Review of drawings and specifications.

Commentary

The location of exits and passageways as related to the H, HC and DHW systems is an important consideration.

4.5.2 Criterion

Identification and location of controls. Main shutoff valves and switches shall be conspicuously marked and placed in easily accessible locations.

Evaluation

Review of drawings and specifications.

4.6 Requirement

Protection of potable water and circulated air. No material, form of construction, fixture, appurtenance or item of equipment shall be employed that will support the growth of micro-organisms or introduce toxic substances, impurities, bacteria or chemicals into potable water and air circulation systems in quantities sufficient to cause disease or harmful physiological effects.

4.6.1 Criterion

Contamination by materials. Materials which come in direct contact with potable water shall not affect the taste, odor or physical quality and appearance of the water in an undesirable manner.

Evaluation

Review of plans and specifications for compliance with the 1962 Edition of the Public Health Service Drinking Water Standards [11].

4.6.2	Criterion	<u>Separation of circulation loops</u>. Circulation loops of subsystems utilizing nonpotable heat transfer fluids shall be separated from the potable water system in such a manner that leakage will not contaminate the potable water supply.
	Evaluation	Review of drawings and specifications.
4.6.3	Criterion	<u>Backflow prevention</u>. Backflow of nonpotable heat transfer fluids into the potable water systems shall be prevented.
	Evaluation	Review of drawings and specifications. Inspection of assembled systems.
	Commentary	Pollution of the potable water supply can occur by way of backflow caused by back pressure and/or backsiphonage within a cross connection between the potable supply and nonpotable fluid in the system. The former type of backflow can occur, for example, from elevated tanks, or pumps. The latter can occur when the potable water supply system is under vacuum such as might occur with a broken street water main. Piping arrangements, backflow prevention devices, and/or air gaps may be used to prevent contamination of the potable water system.
4.6.4	Criterion	<u>Growth of fungi</u>. Components and materials used in the H, HC and DHW systems shall not promote the growth of fungi, mold or mildew.
	Evaluation	When tested in accordance with Appendix D, Section E of the MPS (4900.1 and 4910.1)[1], there should be no evidence of the growth of fungi.
	Commentary	Special consideration should be given to the presence of fungi in air handling systems since such micro-organisms are frequently allergenic. Fungi can feed on some organic materials and generally thrive in warm, moist environments. They can be killed by sufficiently low wavelength ultraviolet radiation but much of this radiation may be absorbed by the earth's atmosphere. It may be possible for fungi to grow on both the interior and exterior of collector components and possibly affect the collector performance.

4.7 Requirement — Excessive surface temperatures. Temperatures of exterior surfaces of the H, HC and DHW systems shall not create a hazard.

4.7.1 Criterion — Protection from heated components. Subassemblies of the H, HC and DHW systems that are accessible, located in areas normally subjected to public traffic and which are maintained at elevated temperatures shall either be insulated to maintain their surface temperatures at or below 140°F at all times during their operation or suitably isolated. Any other exposed areas that are maintained at hazardous temperatures shall be identified with appropriate warning signs.

Evaluation — Review of drawings and specifications.

References

1. HUD Minimum Property Standards, One and Two Family Dwellings (No. 4900.1), U.S. Department of Housing and Urban Development, Washington, D.C. (1973, revised 1974)† and HUD Minimum Property Standards, Multifamily Housing (No. 4910.1), U.S. Department of Housing and Urban Development, Washington, D.C.†

2. Standard for Mobile Homes, ANSI A119.1-1974, American National Standards Institute, New York, N.Y. (1974).

3. Life Safety Code, NFPA No. 101, National Fire Protection Association, Boston, Mass. (1973).*

4. Clearances for Heat Producing Appliances, NFPA No. 89M, National Fire Protection Association, Boston, Mass. (1971).*

5. Air Conditioning and Ventilating Systems, NFPA No. 90A, National Fire Protection Association, Boston, Mass. (1973)* and Warm Air Heating and Air Conditioning Systems, NFPA No. 90B, National Fire Protection Association, Boston, Mass. (1973).*

6. Chimneys, Fireplaces and Vents, NFPA No. 211, National Fire Protection Association, Boston, Mass. (1972).*

7. Gas Appliances and Gas Piping, NFPA No. 54, National Fire Protection Association, Boston, Mass. (1969).*

8. Oil Burning Equipment, NFPA No. 31, National Fire Protection Association, Boston, Mass. (1972).*

9. Fire Tests of Roof Coverings, ASTM E 108-58, American Society for Testing Materials, Philadelphia, Pa. (1970).

10. National Electric Code, National Fire Protection Association, Boston, Mass. (1971).*

11. The Public Health Service Drinking Water Standards, U.S. Department of Health, Education and Welfare, Washington, D.C. (1962).

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*Available from National Fire Protection Association (NFPA), 470 Atlantic Avenue, Boston, Mass. 02210.
†Available from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

5.1 Requirement

Effects of external environment. The systems for heating (H) and combined heating and cooling (HC) and the domestic hot water (DHW) system/subsystem and their various subassemblies shall not be affected by external environmental factors to an extent that will significantly impair their function during their design life.

5.1.1 Criterion

Solar degradation. Components or materials that are exposed to sunlight shall not undergo changes in their properties during their design life that would significantly impair the function of the system.

a. When components or materials are exposed to UV radiation in combination with an intermittent water spray at their maximum "no-flow" temperature, there shall be no signs of excessive deterioration such as cracking, crazing, embrittlement, etching, loss of adhesion, changes in permeability, loss in flexural strength or any other changes that would significantly affect the performance of the components in the system.

b. The collector shall be capable of providing its rated output after exposure to levels and intensities of solar radiation and temperatures that are equivalent to those that would be expected in actual use over the life of the collector.

Evaluation

Documentation of satisfactory long term performance under in-use conditions or engineering analysis. Where adequate existing information is unavailable, testing using either the methodology outlined in Section 03 of the Appendix given at the end of this chapter or other methods which can be shown to meet the intent of the criterion will be used.

Commentary

The transmittance, emittance and absorptance data required to estimate the effects of degradation by solar radiation in reducing the collector efficiency are available for most materials currently being used in collectors.

The maximum "no flow" temperature and other in-use temperatures are discussed in detail in Section 01 of the Appendix at the end of this chapter.

5.1.2 Criterion

Soil corrosion. Components that are intended to be buried in soils shall not degrade under in-use conditions to an extent that their function will be impaired during their design life.

Evaluation

Documentation of satisfactory long term performance under in-use conditions or engineering analysis. Where adequate existing information is unavailable, testing using either the methodology outlined in Section 04 of the Appendix given at the end of this chapter or other methods which can be shown to meet the intent of the criterion will be used.

Protective coverings and/or cathodic protection shall be provided if these protective means are used for protection of the system.

Commentary — This criterion is intended to protect against corrosion which can be caused by soil. The soil conditions will vary from site to site.

5.1.3 Criterion — Airborne pollutants. Components that are exposed to airborne pollutants such as ozone, salt spray, SO_2, NO_x, and/or HCl with or without the presence of moisture shall be resistant to attack by these factors to the extent that these factors shall not significantly impair the performance of the components during their design life.

Evaluation — Documentation of satisfactory long term performance under in-use conditions or engineering analysis. Where adequate existing information is unavailable, testing using either the methodology outlined in Section 05 of the Appendix given at the end of this chapter or other methods which can be shown to meet the intent of the criterion will be used.

The maximum pollutant levels in the area(s) where the system will be installed shall be used to determine the pollutant levels required for testing. If components are to be used in areas where they are not exposed to any or all of these pollutants, tests that are not applicable need not be conducted.

Commentary — Ozone concentrations in normal dry air have been reported to range from 1-5 pphm/volume. However, concentrations of 100 pphm/volume have been reported during very smoggy conditions. Ozone is known to degrade some organic materials but it has little effect on inorganic materials other than metals.

The effects of solar radiation in combination with airborne pollutant may also be an important consideration.

5.1.4 Criterion — Dirt retention on cover plate surface. The collector cover plate surface shall not collect and retain dirt to an extent that would significantly impair the function of the collector during its design life.

Evaluation — Engineering analysis, documentation of satisfactory long-term performance under in-use conditions and review of plans and specifications.

Commentary — The possible collection and retention of dirt by the cover plate and the effect of retained dirt on the collector performance may be significant. The retention of dirt may depend on the tilt angle of the collector. Rainfall and snow melt are generally sufficient to keep the collector cover plates clean.

5.1.5 Criterion

Abrasive wear. The ability of the collector to function at its rated capacity shall not be significantly impaired by the abrasive wear to which its surface will be subjected over its design life.

Evaluation

Engineering analysis, documentation of satisfactory long-term performance under in-use conditions and review of surface hardness specifications for cover plate materials.

Commentary

Test methods which are currently available for measuring abrasion resistance are believed to be too stringent for testing organic collector cover plates. Abrasive wear is expected to present a possible problem in areas subject to wind driven sand.

5.1.6 Criterion

Fluttering by wind. Components that are subject to fluttering by wind shall not degrade under in-use conditions to an extent that their function will be impaired during their design life.

Evaluation

Documentation of satisfactory long-term performance under in-use conditions, engineering analysis, or testing using an experimental verification procedure which can be shown to meet the intent of the criterion.

Commentary

Thin films that increase in brittleness at low temperatures may be particularly susceptible to degradation by fluttering by wind.

5.2 Requirement

Temperature and pressure resistance. Components shall be capable of performing their intended function for their design life when exposed to the temperatures and pressures that can be developed in the system.

5.2.1 Criterion

Thermal degradation. Components shall not thermally degrade to the extent that their function will be reduced below acceptable levels during their design life when exposed to in-use temperatures.

Evaluation

Documentation of satisfactory long term performance under in-use conditions or engineering analysis. Where adequate existing information is unavailable, testing using either the methodology outlined in Section 06 of the Appendix given at the end of this chapter or other methods which can be shown to meet the intent of the criterion will be used.

Commentary

Some organic components which may be used in the system may be particularly susceptible to thermal degradation under prolonged exposure.

5.2.2 Criterion — Deterioration of heat transfer fluids. Except when such changes are allowed by the design of the system, the heat transfer fluid shall not freeze, give rise to excessive precipitation, otherwise lose its homogeneity, boil, change pH or undergo large changes in viscosity when exposed to its intended service temperature and pressure range.

Evaluation — Documentation of satisfactory long term performance under in-use conditions or engineering analysis. Where adequate existing information is unavailable, testing using either the methodology outlined in Section 07 of the Appendix given at the end of this chapter or other methods which can be shown to meet the intent of the criterion will be used.

Commentary — Thermal cycling may cause metastable precipitation to occur. Systems may be pressurized to prevent boiling.

5.2.3 Criterion — Thermal cycling stresses. The H, HC and DHW systems and their various subassemblies shall be capable of withstanding the stresses induced by thermal cycling for their respective design lives.

Evaluation — Documentation of satisfactory long term performance under in-use conditions or engineering analysis. Where adequate existing information is unavailable, testing using either the methodology outlined in Section 08 of the Appendix given at the end of this chapter or other methods which can be shown to meet the intent of the criterion will be used.

Physical restraints that will be imposed on the system in actual use shall be considered when testing is required.

Commentary — This criterion is intended to identify potential problems that may occur as a result of differential thermal movement. Thermal compatibility is especially critical in the case of collectors which may contain large expanses of glazing. Edge flaws in glass may result in cracking of the glass when it is under stress.

5.2.4 Criterion — Leakage. All assemblies or subassemblies which contain heat transfer fluids (other than air) shall not leak when tested at a pressure equal to 150% of the working pressure of the system over the entire service temperature range.

Evaluation — Documentation of satisfactory long term performance under in-use conditions or engineering analysis. Where adequate existing information is unavailable, testing using either the methodology outlined in Section 09 of the Appendix given at the end of this chapter or other methods which can be shown to meet the intent of the criterion will be used.

Commentary — This criterion is intended for materials which may creep or become brittle at service temperatures.

5.2.5 Criterion — Deterioration of gaskets and sealants. Gaskets and sealants in direct contact with heat transfer liquids shall be capable of withstanding repeated cycles consisting of soaking and drying under in-use conditions without significantly impairing their ability to function during their design life.

Evaluation — Documentation of satisfactory long term performance under in-use conditions or engineering analysis. Where adequate existing information is unavailable, testing using either the methodology outlined in Section 10 of the Appendix given at the end of this chapter or other methods which can be shown to meet the intent of the criterion will be used.

Commentary — Gaskets, sealants, and similar organic materials frequently swell when exposed to liquids and shrink upon drying, thus losing their ability to function.

5.2.6 Criterion — Transmission losses due to outgassing. Outgassing of volatiles that will reduce collector performance below specified design values shall not occur when the collector is exposed to the temperature and pressures that will occur in actual service.

Evaluation — Documentation of satisfactory long term performance under in-use conditions or engineering analysis. Where adequate existing information is unavailable, testing using either the methodology outlined in Section 11 of the Appendix given at the end of this chapter or other methods which can be shown to meet the intent of the criterion will be used.

Commentary — Outgassing from components inside the collector could lead to condensation on the underside of the collector cover plates which may reduce the transmissivity of the cover plates.

5.3 Requirement — Chemical compatibility of components. Materials used in the systems and their various subassemblies shall have sufficient chemical compatibility to prevent corrosive wear and deterioration that would significantly shorten the intended service life of components under in-use conditions.

5.3.1 Criterion — Materials/transfer fluid compatibility. Materials designed to be used in contact with heat transfer fluids shall not be corroded by these fluids to the extent that their function will be significantly impaired under in-use conditions during their intended service lives.

Evaluation — Documentation of satisfactory long term performance under in-use conditions or engineering analysis. Where adequate existing information is unavailable, testing using either the methodology outlined in Section 12 of the Appendix given at the end of this chapter or other methods which can be shown to meet the intent of the criterion will be used.

Commentary — Corrosion by heat transfer fluids could be a serious problem in solar energy systems.

5.3.2 Criterion — Corrosion of dissimilar materials. Non-isolated dissimilar materials with or without corrosion resistant finishes, where used either in contact with a transfer fluid, or without such contact, shall not be corroded to the extent that their function will be significantly impaired under in-use conditions during their intended service lives.

Evaluation — Documentation of satisfactory long term performance under in-use conditions or engineering analysis. Where adequate existing information is unavailable, testing using either the methodology outlined in Section 13 of the Appendix given at the end of this chapter or other methods which can be shown to meet the intent of the criterion will be used.

Commentary — The use of corrosion inhibitors or dielectric fittings that electrically isolate dissimilar materials may be desirable. In the case of plastics, plasticizer migration may be a concern. The presence of pinholes in protective coatings may drastically accelerate corrosive action.

5.3.3 Criterion — Corrosion by leachable substances. Chemical substances that can be leached by moisture from any of the materials within the system shall not cause corrosive deterioration of any other components that would significantly impair the ability of these components to perform their intended function over their service lives.

Evaluation — Documentation of satisfactory long term performance under in-use conditions or engineering analysis. Where adequate existing information is unavailable, testing using either the methodology outlined in Section 14 of the Appendix given at the end of this chapter or other methods which can be shown to meet the intent of the criterion will be used.

Commentary — Salts such as those that can be leached by moisture from some types of glass fiber and mineral wool insulation or from organic components may cause corrosion of system components that are in close proximity.

5.3.4 Criterion

Effects of decomposition products. Chemical decomposition products that are expelled from components under in-use conditions shall not cause the degradation of other components within the system to the extent that it would significantly impair their ability to perform their intended function over their service lives.

Evaluation

Documentation of satisfactory long term performance under in-use conditions or engineering analysis. Where adequate existing information is unavailable, testing using either the methodology outlined in Section 15 of the Appendix given at the end of this chapter or other methods which can be shown to meet the intent of the criterion will be used.

Commentary

Some components may yield degradation products during their service life without impairing their function or aesthetic properties. These degradation products could significantly impair the performance of other components in the system.

5.4 Requirement

Components involving moving parts. Components that involve moving parts, with normal maintenance, shall be capable of performing their intended function without excessive wear or deterioration for their service lives.

5.4.1 Criterion

Wear and fatigue. Check valves, pressure regulators, pumps, electrical switches, and similar components shall be capable of operating under in-use conditions for their intended lifespans without exhibiting wear or fatigue that would reduce their performance below specified levels.

Evaluation

Documentation of satisfactory long-term performance under in-use conditions, engineering analysis, or testing using an experimental verification procedure which can be shown to meet the intent of the criterion. Either the number of cycles that would be expected in actual service under in-use conditions, or an accelerated procedure shall be used for experimental verification.

Commentary

In some applications, less expensive components which are readily replaced but have shorter expected lifespans may be more desirable than more reliable but more costly components.

Inclusion of the heat transfer fluid during tests of components with moving parts may be helpful. In particular, very hard crystalline precipitates may be formed from some types of heat transfer fluids and their additives.

Section 01 - Temperature Conditions

Many of the criteria given in this chapter contain reference to the maximum or minimum service temperatures in specifying the temperature at which testing should be performed. For some test conditions, it is advantageous to specify the maximum service temperature that occurs when the heat transfer fluid is flowing through the system; for other test conditions, the maximum service temperature when the heat transfer fluid is not flowing through the system should be used.

The terms used in this chapter to specify temperatures include: 1) maximum "flow" temperature, 2) maximum "no-flow" temperature, 3) maximum service temperature and 4) minimum service temperature. The maximum "flow" temperature of a component refers to the maximum temperature that will be obtained in a component when the heat transfer fluid is flowing through the system. The maximum "no-flow" temperature of a component refers to the maximum temperature that will be obtained in a component when the heat transfer fluid is not flowing through the system. There may be a different maximum "flow" temperature for each component in the system as well as a different maximum "no-flow" temperature. When the test temperature is specified as the maximum service temperature, the test temperature should be the higher of the maximum "flow" or maximum "no-flow" temperatures for the specific component. The minimum service temperature refers to the minimum temperature to which a component will be exposed in actual service, with or without the flow of heat transfer fluid.

The minimum service temperature to which a component in the system will be exposed will generally occur when 1) no solar radiation is falling on the collector, 2) the heat transfer fluid is not flowing through the system and 3) the ambient air temperature is at its lowest level. The no-flow condition mentioned above assumes the flow of the heat transfer fluid will be stopped when solar radiation is not falling on the collector to avoid pumping out heat energy. However, if the flow of fluid is not stopped at night, the minimum service temperature of some components may occur as nocturnal or evaporative cooling takes place.

The maximum service temperature, to which the collector and components that are in intimate contact with it will be exposed, will generally occur when the collector is receiving its maximum level of solar radiation and the heat transfer fluid is not flowing through the collector component. Other components, such as those in the heat transfer and storage subsystems, will generally reach their maximum temperature when the collector is receiving its maximum level of solar radiation and the heat transfer liquid is flowing through the system. The maximum "no-flow" temperature that will occur at various locations in the collector can be calculated if the ambient temperature, the intensity of insolation, the number of cover plates, the back and edge losses, and the absorptivity and emissivity of the absorbant surface and other related factors are known.

The type of information that is required to determine the maximum "no-flow" temperatures in various locations of collectors is shown in Section 02 of this Appendix.

Section 02 - Typical Figures Showing the Maximum "No-Flow" Temperatures in Various Locations of Specific Collector Designs

This Section contains four graphs intended to provide assistance in identifying the maximum "no-flow" temperatures at various locations in the collector. The five curves on each graph represent the maximum "no-flow" temperature for each side of two cover plates and the surface of the absorber. The calculations used to generate the graphs assume: (1) a glass cover plate thickness of 0.125 inches, (2) air space thicknesses of 0.1875 inches both between cover plates and between the absorbent surface and the lower cover plate, (3) zero edge losses, and (4) the incident solar radiation is normal to the collector.

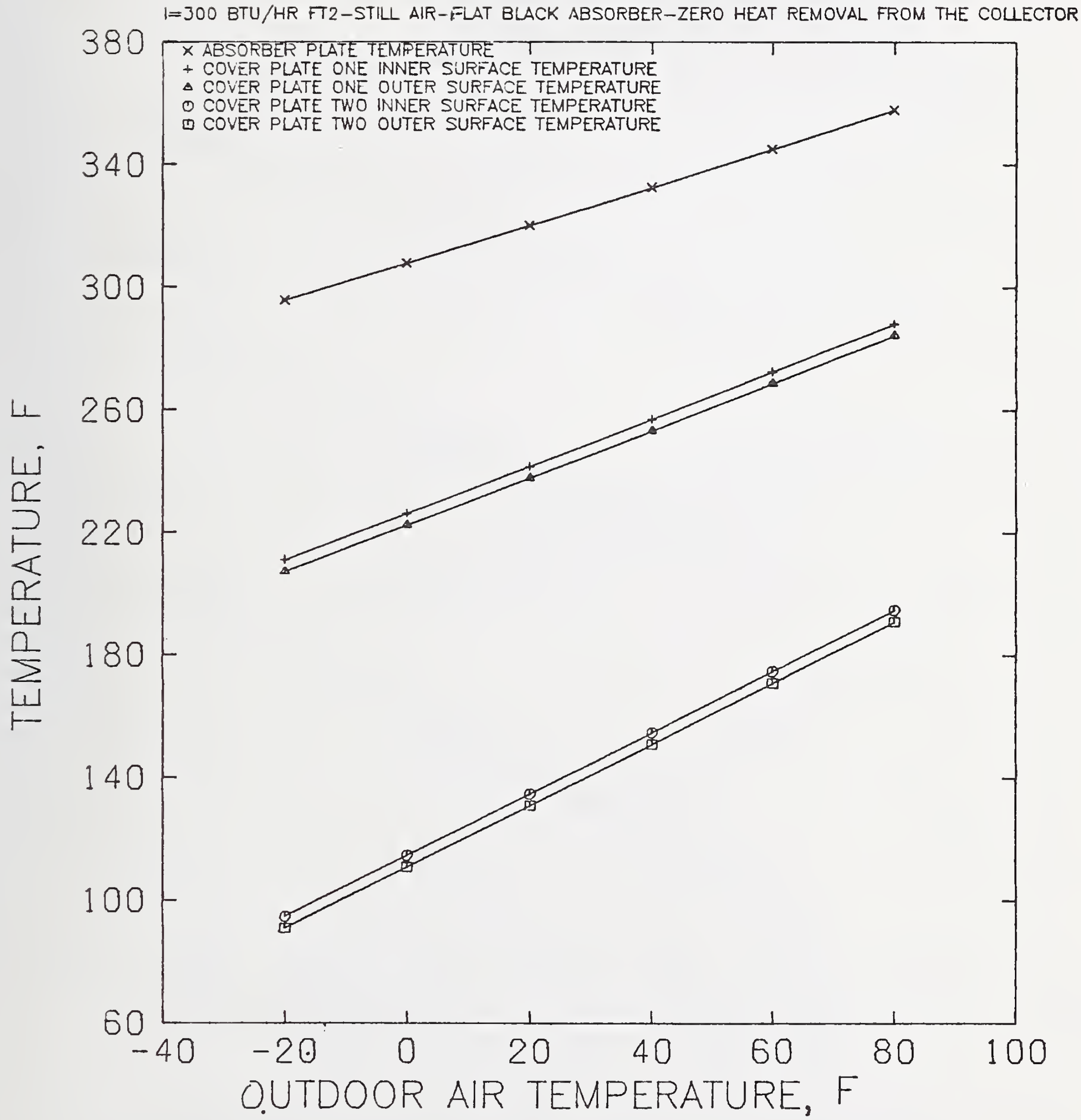

Figure A-1. Temperatures at Various Locations in a Collector with a Flat Black Absorber and Two Glass Cover Plates (Absorptivity = 0.9, Emissivity = 0.9, I = 300 BTU/Hr. ft.^{2})

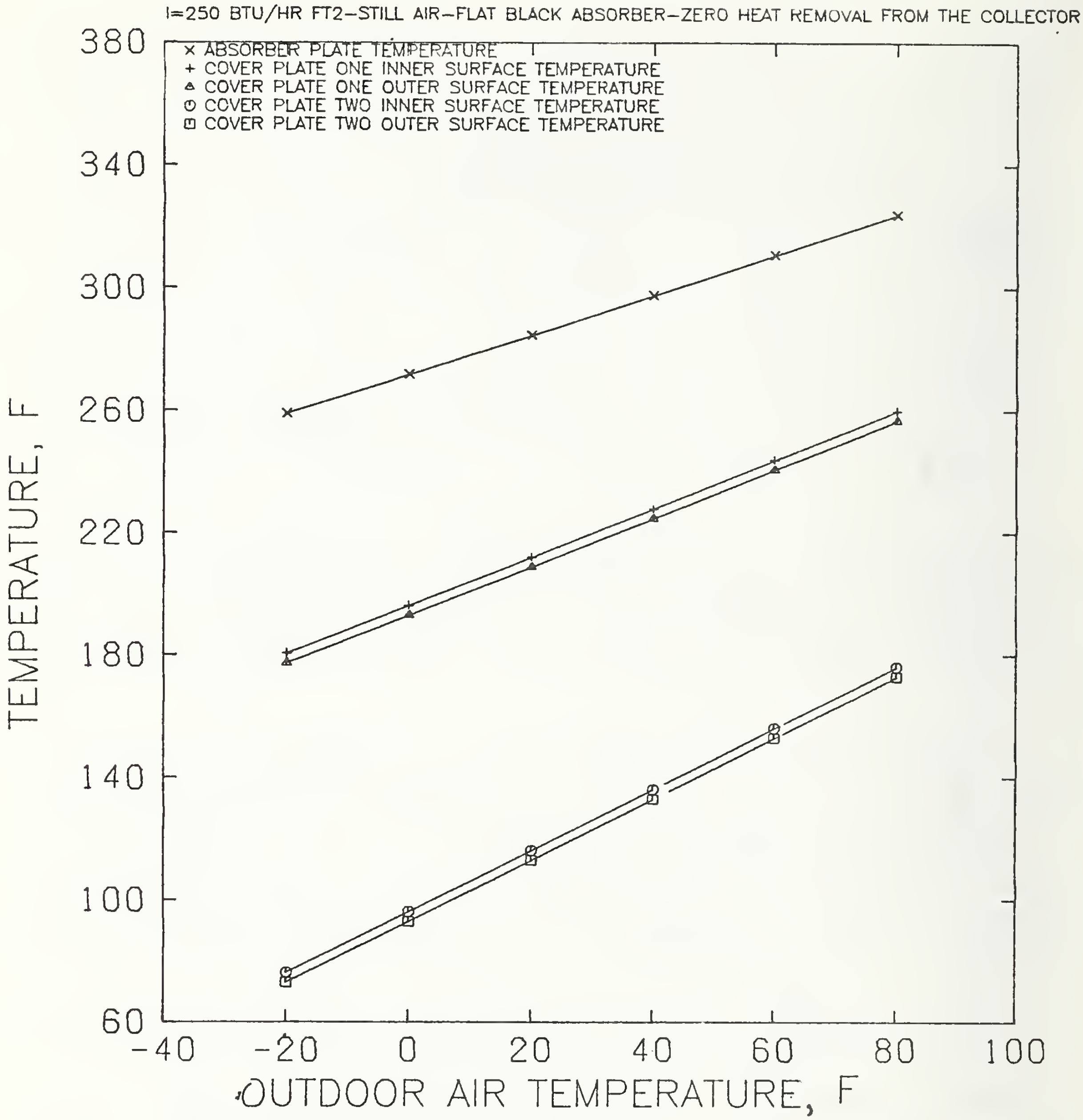

Figure A-2 Temperatures at Various Locations in a Collector with a Flat Black Asborber and Two Glass Cover Plates (Absorptivity = 0.9, Emissivity = 0.9, I = 250 BTU/Hr. ft.^{2})

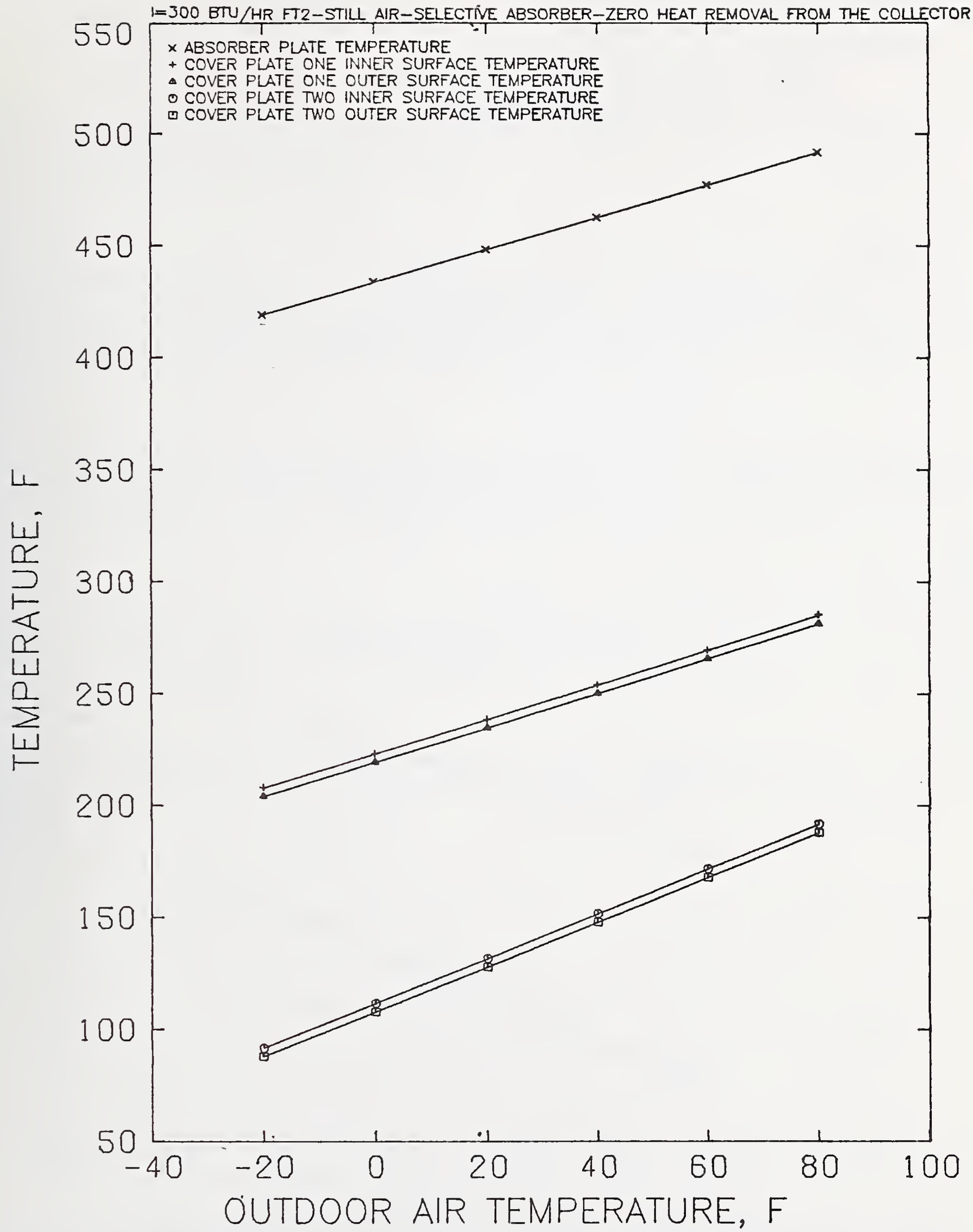

Figure A-3 Temperatures at Various Locations in a Collector with a Selective Absorber and Two Glass Cover Plates (Absorptivity = 0.9, Emissivity = 0.1, I = 300 BTU/Hr. ft.^{2})

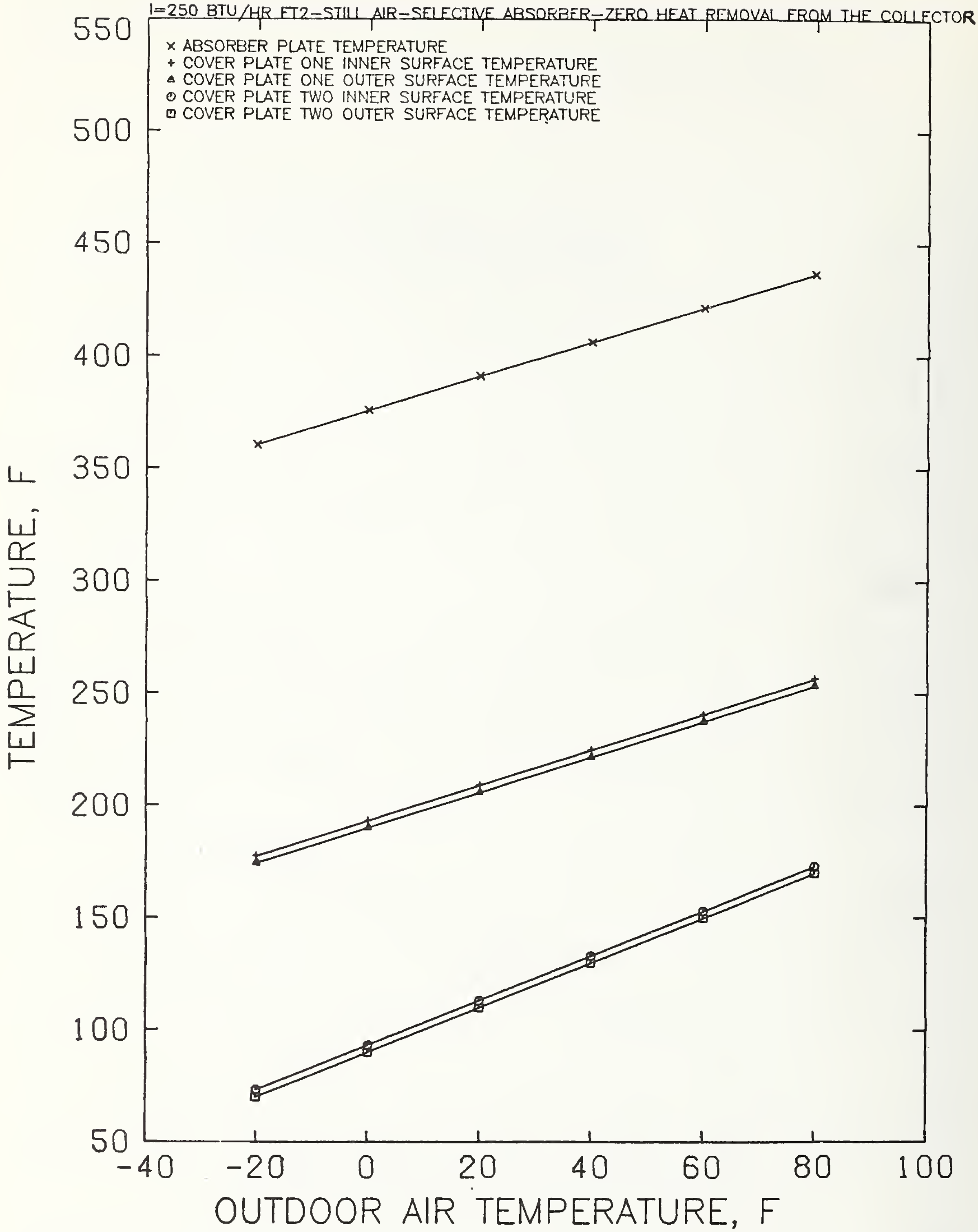

Figure A-4 Temperatures at Various Locations in a Collector with a Selective Absorber and Two Glass Cover Plates (Absorptivity = 0.9, Emissivity = 0.1, I = 250 BTU/Hr. ft.^{2})

Section 03 - Test Methodology: Criteria 5.1.1(a) and 5.1.1(b)

Part A - Test Methodology: Criterion 5.1.1(a)

Test 1

Expose components or materials to simulated solar radiation (such as xenon arc radiation) for a period of 1000 equivalent sun hours. Test specimens shall be heated during the solar radiation exposure, to the maximum "flow" temperature to which they will be subjected in actual service. The exterior surfaces of the components shall be subjected to a water spray for a period of 5 minutes during each 60 minutes of the light exposure.

Test 2

Expose components or materials (not the same specimens used in Test 1) to simulated solar radiation (such as xenon arc radiation) for a period of 100 hours. Test specimens shall be heated, during the solar radiation exposure, to the maximum "no-flow" temperature to which they will be subjected in actual service. The exterior surfaces of the components shall be subjected to a water spray for a period of 5 minutes during each 60 minutes of the light exposure.

ASTM reference methods for Tests 1 and 2 include G26-70, Operating Light and Water Exposure Apparatus (Xenon-Arc Type) for Exposure of Nonmetallic Materials, and D2565-70, Operating Xenon Arc-Type (Water-Cooled) Light and Water Exposure Apparatus for Exposure of Plastics.

At the completion of Tests 1 and 2, the specimens shall exhibit no significant visible signs of deterioration.

In addition to or in lieu of performing Tests 1 and 2 above, outdoor exposure of components and materials to solar radiation may be performed. Outdoor exposure shall consist of at least six months exposure during which the mean daily solar radiation is approximately 500 langleys.*

ASTM reference methods for outdoor exposure tests include:

G7-69T Atmospheric Environmental Exposure Testing of Non-metallic Materials

D1828-70 Atmospheric Exposure of Adhesive Bonded Joints and Structures

D1014-66 (1973) Conducting Exterior Exposure Tests of Paints on Steel

D1006-73 Conducting Exterior Exposure Tests of Paints on Wood

G24-73 Conducting Natural Light Exposures Under Glass

G11-72 Effects of Outdoor Weathering on Pipeline Coatings

D1435-69 Outdoor Weathering of Plastics.

The surfaces of components or materials shall be visually inspected before and after aging to ensure that no signs of excessive deterioration, such as dimensional changes, cracking, chalking, or other visually detectable changes which could significantly affect the performance of the components in the system, are present. The following ASTM evaluative techniques for organic coatings shall be used:

*The mean daily solar radiation for Las Vegas, Nevada and Phoenix, Arizona are 504 and 503 langleys, respectively, according to Environmental Science Services Administration (ESSA) publication "Local Climatological Data. 1971 Annual Summary".

D 714-56 (1970) Evaluating Degree of Blistering of Paints

D 659-44 (1970) Evaluating Degree of Resistance to Chalking of Exterior Paints

D 660-44 (1970) Evaluating Degree of Resistance to Checking of Exterior Paints

D 661-44 (1970) Evaluating Degree of Resistance to Cracking of Exterior Paints

Evaluation techniques, in addition to those related to visual inspection, shall also be used. The methods below represent the types of evaluative techniques that should be used where applicable:

Vapor Transmission

E 96-66 (1972) Water Vapor Transmission of Materials in Sheet Form

C 355-64 (1973) Water Vapor Transmission of Thick Materials

Tensile Strength

D 638-72 Tensile Properties of Plastics

D 897-72 Tensile Properties of Adhesive Bonds

C 297-61 (1970) Tension Test of Flat Sandwich Constructions in Flatwise Plane

Flexure Strength

D 790-71 Flexural Properties of Plastics

C 393-62 (1970) Flexure Test of Flat Sandwich Constructions

Evaluations should be performed on both aged and unaged specimens to establish a basis of comparison.

Commentary

The tests are intended to permit estimations to be made of the effect of solar radiation in degrading collector components and in reducing the collector efficiency. The 1000 equivalent sun hours test time is considered to be equivalent to approximately 6 months of actual solar exposure with an average exposure time of 6 hours per day.

Part B - Test Methodology: Criterion 5.1.1(b)

Method 1 involves the exposure of the collector to solar radiation at an actual test site and measuring the decrease in collector efficiency as a result of the exposure. State-of-the-art collector test methods are referenced in Criterion 1.3.1.

Method 2 involves measuring the deterioration of the window(s) and the absorbant surfaces separately by means of small scale laboratory tests and then incorporating this information into a model developed by ASHRAE which can be used to calculate collector efficiency. The test procedure for Method 2 is given below.

Method 1 for Evaluating the Effects of Solar Degradation on the Performance of the Collector

Test Specimens

The test specimen shall consist of either the entire collector as it would be used in actual service or a thermally equivalent segment of the entire collector.

Aging Procedure

Expose the collector to solar radiation equivalent to that obtained by a one month exposure in Phoenix, Arizona in July with an average exposure time of 6 hours per day normal to the sun. For each 30 days of exposure, the collector shall be exposed one day without the heat transfer fluid.

Test Procedure

Test the collector before and after aging for thermal efficiency. State-of-the-art test methods are referenced in Criterion 1.3.1.

The test specimens shall exhibit no significant change in performance as a result of the aging procedure.

Method 2 for Evaluating the Effects of Solar Degradation on the Performance of the Collector
(Primarily for spectrally selective materials)

Test Specimens

Test specimens shall consist of coupon specimens of the materials to be tested.

Specimens of window materials for aging and evaluating shall consist of the number of windows used in the collector spaced and aligned as they would be in the collector.

Aging Procedure

Specimens shall be exposed to simulated solar radiation* with the spectral intensity in the 300 to 450 nm wavelength range equivalent to the air mass 2 solar spectrum (such as Xenon arc radiation) for a period of 1000 hours at the maximum temperature to which they will be subjected in actual service. The exterior surfaces of the components shall be subjected to a water spray for a period of five minutes during each sixty minutes of the light exposure.

Test Procedures**

Collector Window(s)

1. Measure the total spectral transmittance (including both diffuse and normal radiation) of the window(s) from 300 to 1820 nm.*

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* The specimen shall be mounted perpendicular to the incident radiation.

** Other less sensitive test procedures which are directly integrating are given in ASTM E 424 and E 434.

2. Expose the window(s) to the aging procedure described above.

3. Repeat step 1.

4. Calculate the solar transmittance (τ) determined from transmittance measurements from 300 to 1820 nm for both unaged and aged specimens using the procedure described under Calculations.

Absorbant Surface

Part A

1. Measure the directional reflectance of the absorbant surface in the infrared spectral range from 3 to 20 μm (3000 - 20000 nm).

2. Expose the absorbant surface to the aging procedure described above.

3. Repeat step 1.

4. Convert the reflectance valves to emittance (ε) assuming an opaque coating where: Emittance = 1 - Reflectance.

5. Calculate the total emittance from 3 to 20 μm for both unaged and aged specimens using the procedure described under Calculations.

Part B

1. Measure the directional reflectance of the absorbant surface from 300 to 1820 nm.

2. Expose the absorbant surface to the aging procedure described above.

3. Repeat step 1.

4. Convert the reflectance values to absorptance assuming an opaque coating where: Emittance = Absorptance = 1 - Reflectance.

5. Calculate the solar absorptance (α) from 300 to 1820 nm for both unaged and aged specimens using the procedure described under Calculations.

Calculations

Transmittance

1. Multiply the measured value of transmittance of both aged and unaged window specimens at various wavelengths from 300 to 1820 nm by the value of solar energy (watts/cm^2/nm) at the same wavelengths as read from Figure A-5.

2. Plot energy (watts/cm^2/nm) versus wavelength curves for both aged and unaged specimens.

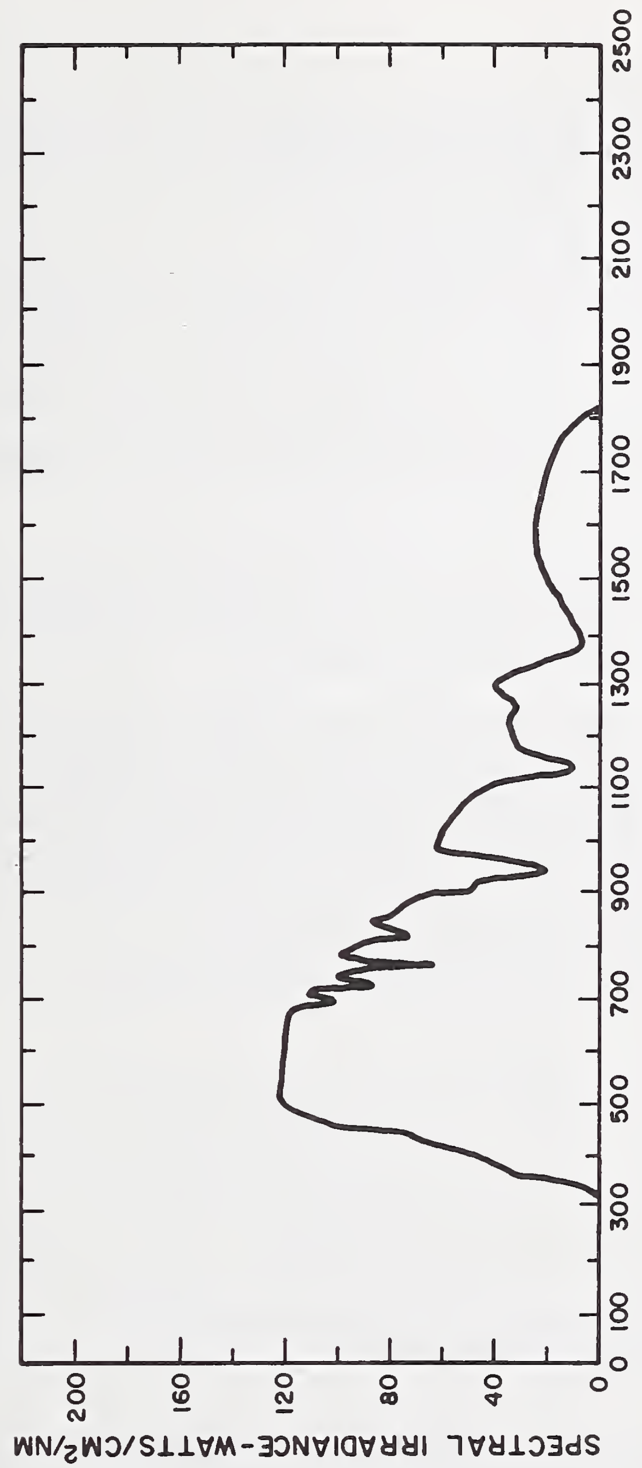

Figure A-5 Spectral Irradiation at Air Mass 2.0

3. Integrate, from 300 to 1820 nm, the area under the curve of Figure A-5 and record the area (E_{T1}).

4. Integrate, from 300 to 1820 nm, the area under the energy versus wavelength curve for unaged specimens and record the area (E_{T2}).

5. Integrate, from 300 to 1820 nm, the area under the energy versus wavelength curve for aged specimens and record the area (E_{T3}).

6. Divide E_{T2} by E_{T1} to obtain the solar transmittance, τ_2, as measured for the unaged window specimen.

7. Divide E_{T3} by E_{T1} to obtain the solar transmittance , τ_3, as measured for the aged window specimen.

8. Incorporate τ_2 and τ_3 into the appropriate equations used in the method to determine the collector efficiency in Criterion 1.3.1.

Total Emittance*

The total emittance of surfaces can vary with temperature because of the change in energy spectral distribution with temperature according to the Planck Radiation Law. The influence of environmental effects on the total emittance can be determined from spectral emittance data by the following procedure.

1. List the spectral emittance and the spectral energy ($w/cm^2/\mu m$) of a black body in at least 0.5 μm wavelength intervals over the wavelength range of 3.0 to 20.0 μm for each temperature. Use a maximum of 10^o C (50^o F) temperature intervals over the temperature range of collector operation (nominally from 38 to 121^oC (100 to 250^oF). Calculate the product of these two values for each wavelength interval.

2. Plot the data obtained from step 1 as a function of wavelength for both aged and unaged specimens and for each temperature. Plot the spectral energy distribution for a black body for each temperature used.

3. Integrate from 3.0 to 20.0 μm, the area under the black body curve for each temperature and record the area ($E_{\varepsilon B}$).

4. Integrate, from 3.0 to 20.0 μm the area under each energy-emittance curve for unaged specimens and record the area ($E_{\varepsilon 1}$) for each temperature.

5. Integrate, from 3.0 to 20.0 μm, the area under each energy-emittance curve for aged specimens and record the area ($E_{\varepsilon 2}$) for each temperature.

6. Divide $E_{\varepsilon 1}$ by $E_{\varepsilon \beta}$ for each temperature to obtain $\varepsilon 1$ for each unaged specimen and $E_{\varepsilon 2}$ by $E_{\varepsilon \beta}$ to obtain $\varepsilon 2$ for each aged specimen.

7. Incorporate $\varepsilon 1$ and $\varepsilon 2$ into the appropriate equations used in the method to determine collector efficiency in Criterion 1.3.1.

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*Total hemispherical emittance can be determined by means of calorimetric techniques. Total normal emittance can be measured with a portable emissometer.

Absorptance

1. Multiply the value of absorptance of both aged and unaged absorbant surface specimens at various wavelengths from 300 to 1820 nm by the value of solar energy (watts/cm^2/nm) at the same wavelengths as read from Figure A-5.

2. Plot energy (watts/cm^2/nm) versus wavelength curves for both aged and unaged specimens.

3. Integrate, from 300 to 1820 nm, the area under the curve of Figure A-5. and record the area ($E_{\alpha\beta}$).

4. Integrate, from 300 to 1820 nm, the area under the energy versus wavelength curve for unaged specimens and record the area ($E_{\alpha 1}$).

5. Integrate, from 300 to 1820 nm, the area under the energy versus wavelength curve for aged specimens and record the area ($E_{\alpha 2}$).

6. Divide $E_{\alpha 1}$ by $E_{\alpha\beta}$ to obtain the solar absorptance, $\alpha 1$, for the unaged window specimen.

7. Divide $E_{\alpha 2}$ by $E_{\alpha\beta}$ to obtain the solar absorptance, $\alpha 2$, for the aged window specimen.

8. Incorporate $\alpha 1$ and $\alpha 2$ into the appropriate equations used in the method to determine collector efficiency in Criterion 1.3.1.

Transmittance or Reflectance by ASTM Method E 424

An alternate calculation method to those presented above is presented in ASTM Method E 424 for transmittance and reflectance. In ASTM E 424, solar energy transmittance or reflectance is calculated by integration using the solar energy distribution for sea level and air mass 2.0. Table A-1 contains twenty selected ordinates for use in the calculations.

Table A-1 Twenty Selected Ordinates for Evaluation of Solar Transmittance or Reflectance at Sea Level*

Ordinate Number	Wavelength (nm)	Ordinate Number	Wavelength (nm)
1	390	11	745
2	444	12	786
3	481	13	831
4	511	14	877
5	543	15	959
6	574	16	1026
7	606	17	1105
8	639	18	1228
9	669	19	1497
10	705	20	1722

*Extracted from ASTM Method E 424

Section 04 - Test Methodology: Criterion 5.1.2

Testing shall be performed for a period of 500 hours, at the maximum service temperature to which the components will be subjected in actual use. During the duration of the test coupon specimens shall be partially immersed in aqueous solutions having a pH equivalent to that found in soil specimens taken from the sites where the systems are intended to be used.

On the basis of visual observation made on the specimens both before and after immersion, there shall be no signs of deterioration that would significantly impair their function.

Section 05 - Test Methodology: Criterion 5.1.3

This section contains test methods to determine the resistance of components to airborne pollutants. Following the test, specimens shall exhibit no signs of deterioration that would significantly impair their performance.

Resistance to Ozone

Coupon specimens of components shall be exposed for 500 hours to an ozone atmosphere of 50 ± 5 pphm/volume in a test chamber at 23 ± 2°C (73.4 ± 3.6°F). After the exposure, the surfaces of the specimens shall be visually examined for signs of deterioration such as cracking, blistering or dimensional changes using a microscope with an eye-piece micrometer at 20X magnification. An ozone test chamber is described in ASTM D 1149-64 (1970), "Accelerated Ozone Cracking of Vulcanized Rubber."

The extent of change of the specimens as a result of the exposure shall be determined by comparing the exposed specimens to control specimens or by comparing the characteristics of the same specimens before and after exposure.

Resistance to Salt Spray

Coupon specimens of components shall be evaluated in accordance with ASTM Standard Method B 117-73. After exposure for 500 hours, the specimens shall be visually examined for signs of deterioration such as cracking, crazing, blistering or pitting. The extent of the change as a result of the exposure shall be determined by comparing the exposed specimens to control specimens or by comparing the characteristics of the same specimens before and after exposure.

Resistance to SO_2, NO_x and HCl

Coupon specimens shall be immersed for 500 hours in aqueous solutions containing 100 ppm of H_2SO_3, HNO_3 and HCl on a one component per test solution basis so that one half the specimen is in the solution. During the immersion, the temperature of the test specimens shall be cycled repetitively as follows: one hour at the maximum service temperature, one hour at 23 ± 2°C (73.4 ± 3.6°F), one hour at the minimum service temperature and one hour at 23 ± 2°C (73.4 ± 3.6°F). After exposure, the specimens shall be visually examined for signs of deterioration such as cracking, crazing, blistering or pitting. The extent of change of the specimens as a result of the exposure shall be determined by comparing the exposed specimens to control specimens or by comparing the characteristics of the same specimens before and after exposure.

Section 06 - Test Methodology: Criterion 5.2.1

Complete components or coupon specimens shall be subjected to heat aging for a period of 500 hours at the maximum service temperature to which they will be exposed in actual service. Components and materials stressed in normal use should be stressed during the exposure. They shall be visually inspected both before and after aging. Both aged and unaged specimens of organic components shall also be tested for tensile strength using ASTM D638-72.

When visually evaluated after exposure at the maximum service temperature, there shall be no significant signs of cracking, crazing, blistering or other deterioration. Also, the specimens shall exhibit no significant loss of strength as a result of the aging.

Section 07 - Test Methodology: Criterion 5.2.2

All heat transfer and storage fluids shall be subjected to the tests below:

Test 1 - Expose the fluids to their maximum "flow" temperature for a period of 500 hours.

Test 2 - Expose the fluids to their minimum service temperature for a period of 500 hours.

Test 3 - Subject the fluids to 100 cycles of cooling and heating with each cycle consisting of the following steps:

a. Cooling to the minimum service temperature over a period of two hours.

b. Holding at the minimum service temperature for two hours.

c. Heating to the maximum "flow" temperature over period of two hours.

d. Holding at the maximum "flow" temperature for two hours.

Periodically, during each test, and at the completion of each test, inspect the fluids visually for signs of undesired changes such as freezing, excessive precipitation, boiling or formation of gas bubbles. Also, before and after each test, measure the pH and the viscosity of the fluid. Boiling tests shall be conducted at service pressures. After the tests, the fluids shall not exhibit changes that would significantly impair their ability to function.

Section 08 - Test Methodology: Criterion 5.2.3

Subject samples of each subassembly of the system, which would normally undergo thermal cycling, to 100 cycles of cooling and heating with each cycle consisting of the following steps:

a. Cooling to the minimum service temperature over a period of two hours.

b. Holding at the minimum service temperature for two hours.

c. Heating to the maximum service temperature over a period of two hours.

d. Holding at the maximum service temperature for two hours.

During the test, the specified minimum or maximum temperature shall be maintained only on the collector plate so that the plate will be the heat source. The temperature of other components shall be permitted to vary as the temperature of the plate changes.

After every third cycle and at the end of the test, visually inspect the components for signs of thermal incompatibility.

After exposure to the repeated cycles at the maximum and minimum service temperatures, there shall be no significant signs of cracking, crazing, loss of adhesion or other deterioration.

Section 09 - Test Methodology: Criterion 5.2.4

Joints and system components which contain heat transfer fluids (other than air) shall be static pressure tested with the heat transfer fluids at a pressure equal to 150% of the working pressure that would occur in the component. Testing shall be performed concurrently for a period of 500 hours at the minimum service temperature and a period of 500 hours at the maximum service temperature.

During and following the pressure tests, visual inspections shall be made to identify evidence of leaks. Also the pressure of the fluid shall be monitored to detect changes due to leakage.

Section 10 - Test Methodology: Criterion 5.2.5

Subject the components to 100 cycles of soaking and drying with each cycle consisting of the following steps:

1. Immerse the components in the heat transfer fluid at the maximum service temperature for a period of four hours.

2. Dry the components at the maximum service temperature for four hours.

After each cycle and at the end of the test visually inspect the components for signs of cracking, swelling or other dimensional changes or loss of adhesion to adjoining components.

Section 11 - Test Methodology: Criterion 5.2.6

Components inside the collector shall be subjected to 100 cycles of heating and cooling with each cycle consisting of the following steps:

a. Heating to the maximum service temperature over a period of two hours at the rated pressure of the system.

b. Holding at the maximum service temperature for two hours.

c. Cooling to the minimum service temperature over a period of two hours at the rated pressure of the system.

d. Holding at the minimum service temperature for two hours at the rated pressure of the system.

After every third cycle, visually inspect the underside of the collector window. If there is visual evidence of condensation, transmittance measurements shall be conducted during the test to determine the rate of loss in optical transmission. In addition, transmittance measurements shall be conducted at the end of 100 cycles for every test specimen.

Section 12 - Test Methodology: Criterion 5.3.1

Coupon specimens, or entire components, shall be immersed in the heat transfer fluid for a period of 500 hours. During the immersion, the temperature of the test specimens or components shall be cycled repetitively as follows: one hour at the maximum service temperature, one hour at 23 ± 2°C (73.4 ± 3.6°F), one hour at the minimum service temperature and one hour at 23 ± 2°C (73.4 ± 3.6°F). Protective coatings shall form a part of the test specimen if they are used in the actual system. Testing shall be followed by visual inspection. Standard TM-01-71, Autoclave Corrosion Testing of Metal in High Temperature Water, of the National Association of Corrosion Engineers or ASTM D2570-73, Simulated Service Corrosion Testing of Engine Coolants, may be used in the evaluation.

Following the test, the test specimens shall not show signs of pitting or exhibit other signs of general corrosive deterioration with the exception of discoloration.

Section 13 - Test Methodology: Criterion 5.3.2

Non-isolated Dissimilar Materials Used in Contact with the Transfer Fluid

Test specimens consisting of dissimilar materials in direct contact with one another shall be immersed in the heat transfer fluid for a period of 500 hours at the maximum service temperature. During the test, the heat transfer fluid shall be circulated. This shall be followed by visual observation. Protective coatings shall be used when they form a part of the component.

Non-isolated Dissimilar Materials Not Used in Contact with the Transfer Fluid

Test specimens consisting of dissimilar materials in direct contact with one another shall be subjected to 100 cycles of heating and cooling. Each cycle shall consist of:

a. Heating to the maximum service temperature over a period of two hours.

b. Holding at the maximum service temperature and a relative humidity of 50% or greater for two hours.

c. Cooling to the minimum service temperature over a period of two hours.

d. Holding at the minimum service temperature for two hours.

Following the exposure, visually inspect the specimens for signs of corrosion.

At the completion of the above tests, specimens shall not show signs of pitting or exhibit other signs of corrosive deterioration, with the exception of discoloration.

Section 14 - Test Methodology: Criterion 5.3.3

Expose components containing leachable substances and components that may be affected by the leachable substances in water or steam for a period of 500 hours at the maximum service temperature. At the end of the exposure, visually inspect the component that may have been affected by the leachable substance for signs of deterioration such as pitting, cracking or dimensional changes.

Section 15 - Test Methodology: Criterion 5.3.4

The evaluation shall consist of two stages. In the first stage, components shall be heated to their maximum service temperatures for two hours and the composition of the decomposition products, if any, shall be determined. Analysis for organic materials could be by infrared spectroscopy or chromatography. Standard wet chemical techniques could be used for inorganic substances.

The second stage of the evaluation shall be performed if the amount and types of decomposition products are significant. The second stage shall consist of subjecting components, that would be exposed to the decomposition products in actual service, to the decomposition products in a test chamber for 100 hours at the maximum service temperature of the components being tested. The concentration of the decomposition products shall be the maximum concentration expected in actual service. During the exposure, moisture shall be added to the test chamber to maintain a relative humidity of 90% or greater.

After the exposure, test specimens shall be visually examined for signs of degradation such as cracking, corrosion and swelling or other dimensional changes.

6.1 Requirement — Accessibility for maintenance and servicing. The systems for heating (H), combined heating and cooling (HC) and the domestic hot water (DHW) system/subsystem shall be designed, constructed, and installed to provide sufficient access for general maintenance, convenient servicing and monitoring of system performance.

6.1.1 Criterion — Access for system maintenance. All individual items of equipment and components of the H, HC and DHW systems which may require periodic examination, adjusting, servicing and/or maintenance shall be accessible for inspection, service, repair, removal or replacement without dismantling of any adjoining major piece of equipment or subsystem.

Evaluation — Review of drawings and specifications.

Commentary — Accessibility as a function of component life is an important consideration.

Information on access provisions is provided in Reference [1].

6.1.2 Criterion — Access for system monitoring. Appropriate access for sensors shall be provided for inspecting and checking essential system parameters such as temperature, pressure and critical voltages.

Evaluation — Review of drawings and specifications for the location of test fittings.

Commentary — Adequately located test fittings will permit system monitoring and expedite the maintenance and repair of equipment.

6.1.3 Criterion — Draining and filling of liquids. To facilitate system or subsystem maintenance and repair, subsystems employing liquids shall be capable of being conveniently filled and drained.

Evaluation — Review of drawings and specifications.

Commentary — The potential buildup of vapor which could create air pockets and thus block or restrict the flow of heat transfer fluids should be considered. (See Criterion 2.1.5)

6.1.4 Criterion — Flushing of liquid subsystems. Suitable connections shall be provided for the flushing (cleaning) of liquid energy transport subsystems.

Evaluation — Review of drawings and specifications.

Commentary — The recommendations of the system manufacturer for cleaning agents compatible with the materials of the system should be followed.

6.1.5 Criterion — Filters. Filters shall be designed and located so that they can be cleaned or replaced with minimum disruption to the system and adjacent equipment. Cleaning frequencies shall be specified by the system manufacturer in the maintenance manual.

Evaluation — Review of drawings and specifications.

6.1.6 Criterion — Potable water shutoff. The DHW system shall be valved to provide shutoff from the cold water supply.

Evaluation — Review of drawings and specifications.

6.2 Requirement — Installation, operation and maintenance manual. A manual shall be provided for the installation, operation and maintenance of the H, HC and DHW systems.

6.2.1 Criterion — Installation instructions. The manual shall include physical, functional and procedural instructions describing how the subassemblies of the H, HC and DHW systems are to be installed.

These instructions shall include descriptions of both interconnections between the system subassemblies and their interfaces and connections with the dwelling and site.

Evaluation — Review of installation instructions.

6.2.2 Criterion — Maintenance and operation instructions. The manual shall completely describe the H, HC and DHW systems, their breakdown into subsystems, their relationship to external systems and elements, their performance characteristics, and their required parts and procedures for meeting specified capabilities.

The manual shall list all parts of the systems, by subsystem, describing as necessary for clear understanding of operation, maintenance, repair and replacement, such characteristics as shapes, dimensions, materials, weights, functions and performance characteristics. The manual shall include a tabulation of those specific performance requirements which are dependent upon specific maintenance procedures. The maintenance procedures, including ordinary, preventive and minor repairs, shall be cross-referenced for all subsystems and organized into a maintenance cycle. The manual shall fully describe operation procedures for all parts of the system including those required for implementation of specified planned changes in mode of operation.

Evaluation — Review of maintenance and operating instructions.

6.2.3 Criterion — Maintenance plan. The manual shall include a comprehensive plan for maintaining the specified performance of the H, HC and DHW systems for their design service lives.

The plan shall include all the necessary ordinary maintenance, preventive maintenance and minor repair work and projections for equipment replacement.

Evaluation — Review of maintenance plan.

6.2.4 Criterion — Replacement parts. Parts, components, special tools and test equipment required for service, repair or replacement shall be commercially available or available from the system or subsystem manufacturer or supplier.

Evaluation — Review of specifications for the availability of parts.

Commentary — This criterion is intended to preclude long periods of system downtime due to the need for the repair or replacement of parts.

6.3 Requirement — Repair and service personnel. The H, HC and DHW systems shall be designed in such a manner that they can be conveniently repaired by qualified service personnel.

6.3.1 Criterion — Maintenance of H and HC systems. The H and HC systems shall be capable of being serviced with a minimum amount of special equipment by a trained HVAC service technician using a maintenance manual.

Evaluation — Review of drawings, specifications, and maintenance instructions.

Commentary — The complexity and design of certain components may require their removal and replacement for repair of the system.

6.3.2 Criterion — Maintenance of DHW system. The DHW system shall be capable of being serviced with a minimum amount of special equipment by a qualified service technician using a maintenance manual.

Evaluation — Review of drawings, specifications, and maintenance instructions.

References

1. Uniform Mechanical Code, International Conference of Building Officials, Whittier, California (1973).

dwellings and sites

7.1 Requirement — Design. The dwelling and site shall utilize materials, designs and construction methods appropriate to the use for which they are intended.

7.1.1 Criterion — Dwelling design. One and two family dwellings and multifamily housing shall be designed and constructed in compliance with the HUD Minimum Property Standards (MPS) [1].

Evaluation — Review of drawings and specifications.

Commentary — A well designed solar energy system which includes the building system must not only collect solar energy but also provide for the efficient storage, distribution and use of that energy. Therefore, solar systems are not merely energy collecting systems, but also energy conserving systems. The standards set in the MPS represent a minimum level of performance. They do not completely address energy conservation and upgrading in this area may be desirable.

There are several approaches that should be considered for the design of buildings that conserve energy. One approach considers the site where energy can be conserved by managing the microclimate and therefore modifying its effect on the building. This can be done through the application of varying degrees of factors such as:

1. Shading devices such as trees and fences
2. Windbreaks or wind funnels
3. Reflecting surfaces such as pools, roads, sidewalks, patios, and walls
4. Humidifiers such as pools and fountains
5. Heat storage materials such as dark pavement

A second approach considers the exterior envelope of the building where energy can be conserved by modifying factors such as:

1. Color
2. Texture
3. Orientation and slope in relation to the wind or sun
4. Shape (in order to vary air pressure, turbulence, and solar exposure)
5. Surface area
6. Thermal conductivity
7. Opening design (size, location, aerodynamics)
8. Weathertightness
9. Shading devices (interior and exterior)
10. Reflectivity (solar and infrared)

In a third approach, by carefully considering the mass of the building and the objects around the building, the rate at which energy is stored and released can be managed e.g., storing energy during the day to be released at night can reduce the thermal load on the building in either a cooling cycle or a heating cycle depending on whether the energy is released inside or outside.

Which combination of options is chosen and how effective the selection will be is dependent on design conditions and design goals.

7.1.2 Criterion — Mobile home design. Mobile homes shall be designed and constructed in compliance with the ANSI A119.1, Standard for Mobile Homes[2].

Evaluation — Review of drawings and specifications.

Commentary — See Commentary: Criterion 7.1.1.

7.1.3 Criterion — Site design. The sites for one and two family dwellings, multifamily housing and mobile homes shall be designed and constructed in compliance with the MPS[1] and/or ANSI A119.3[3], as appropriate.

Evaluation — Review of site plan and specifications.

Commentary — See Commentary: Criterion 7.1.1

7.1.4 Criterion — Passive use of solar energy. Consideration shall be given in the dwelling and site design to the passive utilization of solar energy, wherever practical.

Evaluation — Review of drawings and specifications.

Commentary — Savings can be realized when normally provided components of the building and site can be given an additional use in the heating (H), combined heating and cooling (HC) and domestic hot water (DHW) systems. Considering the building itself as a system for capturing, storing, and utilizing solar energy can provide opportunities for reductions in the building heating or cooling requirements.

7.2 Requirement — Adequate space. The dwelling and site shall provide space to accommodate the H, HC and DHW systems.

7.2.1 Criterion — Collector area. The dwelling and site shall provide sufficient space to install the solar collector.

Evaluation — Review of site plans and architectural drawings showing the area provided for the solar collector and calculations showing the space needed for the collector.

Commentary

This criterion does not require that the solar collector be separate from other solar subsystems but only intends to establish that adequate surface area has to be provided if the collecting element is installed on the building or site. Establishing the slope and area of the collector is a complicated problem and requires consideration of factors such as the following:

1. Climatic region
2. Collector orientation and tilt angles
3. Collector exposure to wind
4. Amount of energy supplied or released by the collector
5. Collector mounting (free standing or integrated with the building)
6. Efficiency of collector
7. Type of auxiliary energy used

7.2.2 Criterion

<u>Storage area</u>. Where thermal storage is required, the dwelling and/or site shall provide sufficient space to install the storage subsystem.

Evaluation

Review of architectural drawings and site plans showing the space provided for thermal storage and calculations showing the volume required for storage.

Commentary

This criterion does not require that storage be separate from other solar subsystems it is intended to ensure that a sufficient volume is provided for storage.

The amount of storage required will vary with factors such as:

1. The heat capacity of the storage medium
2. Climatic region
3. Amount of energy supplied or released by the collector
4. Efficiency of the collector
5. Heat losses in the system
6. Design load of H, HC and DHW systems

7.2.3 Criterion

<u>Utility chases</u>. When the energy transport subsystem is installed within floors, walls, ceilings or utility chases, adequate space shall be provided for installation.

Evaluation

Review of the mechanical drawings showing the layout of the energy transport subsystem and typical architectural sections for walls, floors and roof.

Commentary

A preferred location for piping and ducts in walls may be within interior walls rather than in exterior walls. This is particularly true for those pipes and ducts delivering domestic hot water, heating or cooling to the building so that losses and gains therefrom will be contained within the conditioned space.

7.3	Requirement	Functioning of dwelling and site. The use of the dwelling and site shall not be substantially impaired by the H, HC and DHW systems.
7.3.1	Criterion	Space use. A location shall be provided for solar subsystems that will not significantly impair the use of required exterior or interior spaces, as defined in the MPS[1].
	Evaluation	Review of site plans and architectural floor plans showing the location of solar subsystems.
	Commentary	The space provided for the solar subsystems should be in addition to that required by the MPS and the location of the subsystems should not unduly interfere with the use of a space, the required headroom in a space, or required circulation through a space. The system should not unduly interfere with trash removal, furniture moving, the servicing of mechanical equipment, or the normal movement of people and vehicles. Since a collector may reflect a large percentage of the incident solar radiation at high incident angles, the possibility of reflecting solar rays onto areas where people congregate should be investigated.
7.3.2	Criterion	Shading of adjacent structures. The dwelling and its solar subsystems shall not significantly infringe on the ability of adjacent dwellings and their solar subsystems to collect solar energy or provide natural interior light.
	Evaluation	Review of calculations and a site plan showing the areas of adjacent buildings shaded on June 21 (for cooling) and December 22 (for heating) between 10 AM and 2 PM solar time. Other days may be used if deemed appropriate.
	Commentary	Data are available for calculating shading angles as a function of the time of day and year[4] [5].
7.3.3	Criterion	Impact on environment. A site location shall be provided for the dwelling and its solar subsystems which will not significantly endanger the natural environment.
	Evaluation	Review of drawings and a report on the negative effects of the building and its solar subsystems on drainage, vegetation, microclimate and wildlife.

Commentary

This criterion does not require that existing conditions should be maintained but that environmental degradation should be prevented which cannot be neutralized within a year by nature or which could set up a chain reaction affecting a much larger area than the individual building site. Several examples can be cited that could cause such conditions to exist: (1) if runoff from a large collector is not collected and carried away in a drainage system it could for certain soil conditions cause excessive erosion; (2) if the reflected rays from a collector or the shade created by a collector killed existing vegetation and prevented the growth of new vegetation, large areas of soil might be exposed to excessive runoff and if erosion resulted, it could represent a hazard to surrounding streams; (3) the location provided for, and the installation of solar subsystems may make it necessary to cut down trees or may kill them after construction as a result of compaction, drying, sunburn, overturning, grade change, root pruning or other reasons.

7.3.4 Criterion

View. The location of solar subsystems shall not unnecessarily block interior or exterior views of the site, unless they are intended as an integrated part of that view.

Evaluation

Review of architectural and site plans.

Commentary

Even well designed subsystems can be an undesirable obstruction to views from the house or site unless they are integrated into the view, as might be the case with a fence used as a collector.

References

1. HUD Minimum Property Standards, One and Two Family Dwellings (No. 4900.1), U.S. Department of Housing and Urban Development, Washington, D.C. (1973, revised 1974) and HUD Minimum Property Standards, Multifamily Housing (No. 4910.1), U.S. Department of Housing and Urban Development, Washington, D.C. (1973).*

2. Standard for Mobile Homes, ANSI A119.1-1974, American National Standards Institute, New York, N.Y. (1974).

3. Standard for Mobile Home Parks, ANSI A119.3-1973, American National Standards Institute, New York, N.Y. (1973).

4. Aronin, J., Climate and Architecture, pp. 27-61, Reinhold Publishing Company, New York, N.Y. (1953).

5. Givoni, B., Man, Climate and Architecture, pp. 185-188, Elsevier Publishing Company, New York, N.Y. (1969).

*Available from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

8.1 Requirement — Interference with mechanical operation. The dwelling and site elements shall not prevent the proper mechanical functioning of the H, HC and DHW systems.

8.1.1 Criterion — Blockage of solar subsystems. Building and planting arrangements shall be integrated with the installation of solar subsystems to avoid interference with their mechanical function.

Evaluation — Review of mechanical drawings and site plans showing the location of mechanical equipment, air intakes, outlet vents, vegetation, walls and any other obstructions which might affect the operation of the H, HC or DHW systems.

Commentary — Existing vegetation and future growth of that vegetation can become a problem in the functioning of mechanical equipment, air intakes and vents. For example plants might block and therefore reduce the efficiency of a fan or a compressor-condensor unit. On the other hand vegetation can be used to advantage to reduce cooling load as a sunshade.

8.1.2 Criterion — Shading of collector. The location provided for the collector shall not be shaded for more than the specified period allowed for in the design.

Evaluation — Review of calculations or projected elevations of the collector estimating the area of the collector shaded by mechanical equipment, chimneys, vents, trees and other elements on June 21 (for cooling) and December 22 (for heating), or other appropriate days between 10 AM and 2 PM solar time.

Commentary — In locating trees in order to minimize the amount of shade falling on the collector, the designer may not be able to effectively use shade trees to improve the microclimate. Data are available for calculating shading angles as a function of the time of day and year[1] [2]. The possible shading of solar subsystems by snow buildup, e.g., when the collector is mounted on a flat roof or on the ground, is also an important consideration.

8.1.3 Criterion — Sensor location. A location shall be provided for interior and exterior control sensors which will allow the detection of appropriate changes in the system and the environment without unnecessary interference from factors such as shade, drafts and vibrations.

Evaluation — Review of architectural floor plans or electrical/mechanical drawings showing the location and elevation of control sensing equipment. If sensing equipment is located on the exterior of a building, exterior elevations showing the location and elevation of control sensing equipment and site plans shall be provided.

8.2	Requirement	Mechanical and electrical functioning of dwelling and site. The mechanical and electrical operation of the dwelling or site shall not be significantly affected by the H, HC and DHW systems.
8.2.1	Criterion	Exhaust and venting. The location provided for solar subsystems shall not interfere aerodynamically or physically with the venting of the dwelling's plumbing systems or the exhaust of the dwelling's mechanical systems to the extent that their intended function is impaired.
	Evaluation	Review of mechanical drawings showing the location of solar subsystems, plumbing vents and mechanical exhausts.
	Commentary	The wind conditions created around chimneys, flues, plumbing vents, mechanical exhausts and condensers by the presence of solar subsystems should be examined for possible interference with the mechanical operation of such elements.
8.2.2	Criterion	Utilities. The location and installation of solar subsystems shall not interfere with the safe operation of existing or proposed utility systems.
	Evaluation	Review of utility plan and site plan.
	Commentary	Underground potable water piping serving an array of solar collectors installed remote from the building could transmit pollution from sewerage system to the potable water system. A horizontal separation of at least 10 feet from a septic tank drainage field and 12 inches from a sewer line is common practice for pipes carrying potable water.
8.3	Requirement	Mechanical and electrical functioning of connections. The connections between the H, HC, and DHW systems and the dwelling or site shall function mechanically or electrically as intended.
8.3.1	Criterion	Plumbing connections. Plumbing connections between the solar subsystems and water service or waste disposal systems shall be in accordance with the MPS[3] or ANSI A119.1[4], as applicable.
	Evaluation	Review of mechanical drawings and any details or specifications related to plumbing connections.
	Commentary	Particular attention should be given to making sure that plumbing connections are dimensionally coordinated, that pipe sizes and threads are compatible, and that changes in direction do not unduly restrict the flow of fluid.

8.3.2 Criterion — Electrical connections. Electrical connections between the solar subsystems and the electrical system of the dwelling or electrical service to the dwelling shall be in accordance with the MPS[3] or ANSI A119.1[4], as applicable.

Evaluation — Review of electrical/mechanical drawings and details or specifications related to electrical connections.

Commentary — Particular attention should be given to making sure that electrical connections do not overload the electrical service and that electrical connections are mechanically secure and do not create a fire hazard.

References

1. Aronin, J., Climate and Architecture, pp. 27-61, Reinhold Publishing Company, New York, N.Y. (1953).

2. Givoni, B., Man, Climate and Architecture, pp. 185-188, Elsevier Publishing Company, New York, N.Y. (1969).

3. HUD Minimum Property Standards, One and Two Family Dwellings (No. 4900.1), U.S. Department of Housing and Urban Development, Washington, D.C.* (1973, revised 1974) and HUD Minimum Property Standards, Multifamily Housing (No. 4910.1), U.S. Department of Housing and Urban Development, Washington, D.C.* (1973).

4. Standard for Mobile Homes, ANSI A119.1-1974, American National Standards Institute, New York, N.Y. (1974).

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9.1 Requirement — Structural integrity of H, HC and DHW systems. The dwelling or site shall not unduly affect the structural integrity of the H, HC and DHW systems.

9.1.1 Criterion — Movement in adjacent structures. The locations provided for the installation of solar subsystems shall take into account possible movements in adjacent structures which could cause damage.

Evaluation — Review of site plans and structural drawings.

Commentary — The possibility of stresses being imposed by thermal expansion or contraction, wind movements or foundation settlement of adjacent structures should be considered.

9.2 Requirement — Structural integrity of dwelling. The structural integrity of dwelling and site elements shall not be unduly affected by the H, HC and DHW systems.

9.2.1 Criterion — Loads. In addition to basic design loads, dwelling and site elements shall be capable of carrying the increased loads imposed by solar subsystems.

Evaluation — Review of structural drawings, specifications and design calculations taking into consideration the loads set forth in Chapter 3, Structural, Systems and Components.

9.2.2 Criterion — Penetration of structural members. Penetrations in structural elements required for installing solar subsystems shall be located where they will not reduce the strength of structural members below allowable design values.

Evaluation — Review of structural and mechanical drawings.

Commentary — This criterion is intended to prevent holes which are cut for the installation of pipes, ducts, conduit wires and other mechanical equipment from reducing the required strength of structural members.

9.3 Requirement — Structural connections. Structural connections between solar subsystems and the dwelling or site elements shall be capable of carrying imposed loads.

9.3.1 Criterion — Structural connections. Structural connections between solar subsystems and the dwelling or site elements shall be capable of transmitting sustained loads as specified in the design.

Evaluation — Review of structural drawings showing connection details, specifications and design calculations.

Commentary — This criterion deals not only with the connection of major structural elements but with brackets or other supports used for mounting solar subsystems on a building.

9.3.2 Criterion — Brittle subsystems. Large brittle elements of the solar subsystems shall be attached by devices or materials capable of accommodating the maximum movement that would occur in normal use.

Evaluation — Review of structural connection details and specifications.

9.3.3 Criterion — Strength and stiffness. When solar subsystems are mounted on dwelling or site elements, the structural supporting elements shall be of sufficient strength and stiffness to accept the loads imposed.

Evaluation — Review of structural details and calculations.

Commentary — This criterion is intended to ensure that the local area around the connection of a solar subsystem is structurally designed. Criterion 9.2.1 is intended to insure that those loads are carried by the building and its footings.

10.1	Requirement	<u>Safety of dwelling and site</u>. The safe operation of the dwelling or site shall not be affected by the H, HC and DHW systems.
10.1.1	Criterion	<u>Fire</u>. The location of solar subsystems shall not be detrimental to the fire safety of the dwelling or site.
	Evaluation	Review of site plans and architectural, structural, mechanical and electrical drawings for compliance with applicable fire safety practices as described in the HUD MPS[1] and ANSI A119.1[2].
	Commentary	When solar subsystems are located on the site, circulation paths should be checked to see that interference with the movement of fire fighting equipment or with the emergency evacuation of a building is minimized. When system components are mounted on the building or made an integral part of the building, the fire safety of the building's occupants must be maintained. Traditionally, fire fighters have used the roofs of buildings for gaining access, venting and rescuing people from fires.
10.1.2	Criterion	<u>Accidents</u>. The location provided for solar subsystems shall not increase the accident potential to a greater extent than would be expected for a conventional non-solar house.
	Evaluation	Review of architectural plans and site plans showing the location of solar subsystems and mechanical drawing details of the solar subsystems.
	Commentary	Several examples can be given of how the presence of solar subsystems might increase accident potential: (1) Snow and ice accumulations on the collector could present a hazard to pedestrians below, (2) reflected rays from the collector could be distracting to drivers on adjacent highways or annoying to the occupants of nearby buildings, and (3) the ground around a storage unit might settle, creating a hazard because of the uneven ground.

References

1. HUD Minimum Property Standards, One and Two Family Dwellings (No. 4900.1), U.S. Department of Housing and Urban Development, Washington, D.C.* (1973, revised 1974) and HUD Minimum Property Standards, Multifamily Housing (No. 4910.1), U.S. Department of Housing and Urban Development, Washington, D.C.* (1973).

2. Standard for Mobile Homes, ANSI A119.1-1974, American National Standards Institute, New York, N.Y. (1974).

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11.1 Requirement — Durability and reliability of H, HC and DHW systems. The dwelling and site shall not reduce the durability or reliability of the H, HC and DHW systems to an extent that would significantly impair their intended function.

11.1.1 Criterion — Vegetation. In locating plants, consideration shall be given to the effects that their sap, roots, or growth could have on the durability and reliability of the H, HC and DHW systems.

Evaluation — Review of site plans showing the location of existing and proposed plants and the location of the solar subsystems.

11.2 Requirement — Durability and reliability of dwelling and site. The durability or reliability of the dwelling system and site elements shall not be reduced by the H, HC and DHW systems to an extent that would significantly impair their intended function.

11.2.1 Criterion — Chemical corrosion. Solar subsystems shall not cause chemical corrosion of the building or site elements to an extent that would significantly impair their intended performance.

Evaluation — See Evaluation: Criteria 5.3.3 and 5.3.4 in Chapter Five, Systems and Components.

11.2.2 Criterion — Heat and moisture. Roof mounted solar subsystems shall not cause a buildup of heat or moisture that would cause excessive deterioration of the roofing system or other components of the dwelling.

Evaluation — Review of architectural plans, specifications and calculations for temperature buildup caused by solar subsystems.

Commentary — The presence of the collector can cause abnormal heat rises which could cause thermal degradation and the buildup of moisture which could cause rotting.

11.2.3 Criterion — Exterior penetrations. Openings in the dwelling through which piping, ducting and/or wiring are passed shall be made watertight.

Evaluation — Review of architectural details and specifications for penetrations through the exterior walls and roof.

11.3 Requirement — Durability and reliability of connections. The connections between the H, HC and DHW systems and the dwelling that are exposed to external environmental factors shall not undergo changes that will impair their functions.

11.3.1 Criterion — Material compatibility. Connector materials shall be chemically and physically compatible under in-use conditions.

Evaluation — See Evaluation: Criterion 5.3.2 in Chapter Five, Systems and Components.

12.1 Requirement — Maintainability of H, HC and DHW systems. The dwelling or site shall not prevent the practical maintainability of the H, HC and DHW systems.

12.1.1 Criterion — Accessibility. Solar subsystems shall be accessible for maintenance.

Evaluation — Review of site plans and architectural drawings.

Commentary — Solar subsystems should be accessible without trespassing on adjoining property and should not be located unnecessarily under buildings or roads, behind mechanical equipment or in other places which are difficult to reach for maintenance. The energy transport system should be accessible for maintenance without disassembling any major structural or mechanical elements. There should be sufficient room around components to permit their examination, adjusting, servicing and/or maintenance. Accessibility for repair and maintenance should reflect the expected life of the component and frequency of routine maintenance required. An element with a shorter maintenance cycle or life expectancy should be more accessible than one that has a longer maintenance cycle or life expectancy.

12.1.2 Criterion — Misuse. Solar subsystems shall be located where the potential for their misuse is minimized.

Evaluation — Review of site plans showing the location of recreational facilities, protective screening, roads, sidewalks, and solar subsystems.

Commentary — The proximity of solar subsystems to playgrounds and sidewalks should be examined to minimize the potential for misuse or vandalism. In addition, equipment which should only be adjusted by skilled personnel should not be located in areas subjected to normal pedestrian traffic.

12.1.3 Criterion — Permanent maintenance accessories. Permanent maintenance accessories such as hose bibs, drains and ladder supports necessary for the maintenance of the H, HC and DHW systems shall be provided.

Evaluation — Review of maintenance plans and architectural drawings showing the location of drains, ladder supports and other permanent maintenance accessories.

Commentary — The area around solar subsystems should be provided with necessary drains, hose bibs and surfaces for supporting ladders or other equipment that might be needed to service the solar subsystems.

12.2 Requirement — Maintainability of dwelling and site. The practical maintainability of the dwelling or site shall not be significantly impaired by the H, HC and DHW systems.

12.2.1 Criterion — Accessibility. The location of the solar subsystems shall not impair accessibility needed to maintain the dwelling or site.

Evaluation — Review of maintenance plans, site plans and architectural and mechanical drawings.

Commentary — The location of the underground elements should be examined both to insure that they can be maintained without trespassing on adjoining property and to insure that they do not prevent digging, truck access, etc., necessary to maintain the building or site.

12.2.2 Criterion — Ice dams. The presence of a solar subsystem shall not create the potential for significant ice damming which might cause roof leakage.

Evaluation — Review of architectural roof plan and details for roof-installed solar components.

Commentary — Ice sliding off a collector, for example, can create a dam behind which water could accumulate and cause roof leakage.

12.3 Requirement — Connections. The connections between the H, HC and DHW systems and the dwelling or site shall be maintainable.

12.3.1 Criterion — Accessibility. Connections which require maintenance shall be accessible without disassembling major portions of the solar subsystems, the dwelling or the site elements.

Evaluation — Review of maintenance plans and mechanical, electrical and structural connection details and specifications.

13.1 Requirement — Visual characteristerics of dwelling and site. Consideration shall be given to the effects on the visual characteristics of the existing and proposed environment caused by the installation of a solar dwelling.

13.1.1 Criterion — Dwelling. The effects of the solar subsystems on the mass, scale, grid pattern, texture and color of the building shall be considered.

Evaluation — Review of site plans and architectural plans, elevations, models and renderings of the building and its solar subsystems.

13.1.2 Criterion — Neighborhood. Consideration shall be given to the relationship between solar dwellings and the surrounding neighborhood.

Evaluation — Review of site plans, elevations, photographs of neighboring buildings, models and renderings of the building, its surrounding neighborhood and solar subsystems.

Glossary*

Absorptance - The ratio of the amount of radiation absorbed by a surface to the amount of radiation incident upon it.

Absorptivity - The capacity of a material to absorb radiant energy.

Air chamber - A closed section of pipe or a container filled with air entrapped at atmospheric pressure which when mounted in a water supply line absorbs the pressure surges caused by the rapid opening and closing of valves.

Air gap separation - The unobstructed vertical distance through the free atmosphere between the lowest opening from any pipe or faucet supplying water to a tank, plumbing fixture, or other device and the flood level rim of the receptacle.

Auxiliary energy subsystem - Equipment utilizing conventional energy sources both to supplement the output provided by the solar energy system as required by the design conditions, and to provide full energy backup requirements during periods when the solar H, HC or DHW systems are inoperable.

Back pressure - A form of backflow caused by a pump, elevated tank, boiler, or other means that could create pressure within the system greater than the supply pressure of a fluid.

Backflow - The reverse flow of liquids, gases, or substances into the distributing pipe lines of a potable supply of water. Backflow may occur under two conditions - pressure greater than atmospheric (see "Back pressure"), and pressure that is subatmospheric (see "Backsiphonage").

Backsiphonage - A form of backflow due to a negative or subatmospheric pressure.

Cathodic protection - The process of providing corrosion protection against electrolytic reactions that could be deleterious to the performance of the protected material or component.

Chemical compatibility - The ability of materials and components in contact with each other to resist mutual chemical degradation, such as that caused by electrolytic action or plasticizer migration.

Climate - The prevailing or average weather conditions of a geographic area or region as shown by temperature and meteorological changes over a period of years.

Collector efficiency (instantaneous) - The amount of energy removed by the transfer fluid per unit of aperture (entrance window area) over a 15-minute period divided by the total incident solar radiation onto the same collector area for the 15-minute period.

Collector subsystem - The assembly used for absorbing solar radiation, converting it into useful thermal energy, and transferring the thermal energy to a heat transfer fluid.

*Additional definitions can be found in the HUD Minimum Property Standards (4900.1 and 4910.1)

Components - The lowest identifiable elements of a solar heating or heating and cooling subsystem, such as valves, piping, controls, containers, etc.

Control subsystem - That assembly of devices and their electrical, pneumatic or hydraulic auxiliaries used to regulate the processes of collecting, transporting, storing and utilizing energy in response to the thermal, safety, and health requirements of the building occupants.

Cooling degree days - The number of degrees that the daily mean temperature is above 65 degrees F.

Creep - A time-dependent deformation caused by sustained loads. (See "Sustained load.")

Cross-connection - Any connection between a potable water system and nonpotable source or system through which backflow can occur. (See "Backflow.")

Cyclic load - A service load whose magnitude and/or direction are subject to time-dependent variation.

Dead-weight tester - A standard device used for calibrating gages.

Design life - The period of time during which an H, HC and/or DHW system is expected to perform its intended function without requiring major maintenance or replacement.

Dielectric fitting - An insulating or nonconducting fitting used to isolate electrochemically dissimilar materials.

Domestic hot water (DHW) system - The complete assembly of subsystems and components necessary to convert solar energy into thermal energy and use this energy in combination with auxiliary energy, where required, to provide hot water in the building.

Ease of ignition - The flame exposure time required to produce sustained flaming of a representative specimen of material from a controlled impinging flame source.

Electrical distribution subsystem - All electrical conductors and equipment installed in the H, HC, and/or DHW systems, including supply conductors for operation of the systems.

Emittance - The ratio of the radiant energy emitted by a body to the energy emitted by a black body at the same temperature.

Energy transport subsystem - Those portions of the H, HC or DHW systems which transport energy throughout the system.

Environmental impact statement - A report of any effects that the system component or building could have on the site and its surroundings.

Expansive soil - A soil which exhibits an increase in volume with an increase in moisture content.

Failure (structural) - Failure of a structure or any structural element is defined as one of the following

(a) Sudden, locally-increased curvature, major spalling, or structural collapse.

(b) The inability of the structure to resist a further increase in load.

(c) An increase in deflection of no less than the maximum allowable deflection under service load conditions, occurring during any 10-minute period after application of the superimposed load without an increase in the applied load.

Fluid requiring special handling - Fluid having a degree of toxicity such that it is categorized as a "highly toxic substance" or a "toxic substance" as defined by paragraphs 191.1(e) and (f) of the Hazardous Substances Act, Regulations, Part 191, Chapter I, Title 21 [A]; fluid having a degree of flammability such that it is categorized as a "flammable substance" or an "extremely flammable substance" as defined by application of the Tagliabue Open-Cup Flash Point Test (stated in the Act).

Heat actuated cooling - The use of thermal energy to initiate a thermodynamic cycle which results in lowering the temperature of a heat transfer fluid, which in turn is used to lower the indoor air temperature.

Heat capacity - The amount of heat necessary to raise the temperature of a given mass one degree.

Heat transfer medium - A fluid used in the transport of thermal energy.

Heating degree days - The number of degrees that the daily mean temperature is below 65 degrees F.

Heating (H) system - The complete assembly of subsystems and components necessary to convert solar energy into thermal energy and use this energy in combination with auxiliary energy, where required, for heating purposes.

Heating and cooling (HC) system - The complete assembly of subsystems and components necessary to convert solar energy into thermal energy and use this energy in combination with auxiliary energy, where required, for combined heating and cooling purposes.

Humidity, relative - The ratio of the mol fraction of water vapor to the mol fraction of water vapor present in saturated air at the same temperature and barometric pressure.

In-service conditions - The conditions to which a solar heating and cooling system and its components will be exposed during their operational lifetimes.

Integral system - A dwelling design into which a solar heating or combined solar heating and cooling system has been integrated into the building.

Load factors - Multipliers by which design loads are increased in order to obtain the loads to be used in ultimate strength design of structural elements.

Maximum "flow" temperature - The maximum temperature that will be obtained in a component when the heat transfer fluid is flowing through the system.

Maximum "no-flow" temperature - The maximum temperature that will be obtained in a component when the heat transfer fluid is not flowing through the system.

Maximum service temperature - The maximum temperature to which a component will be exposed in actual service, either with or without the flow of heat transfer fluid.

Metastable precipitation - The precipitation of solid matter from a solution where such precipitation would not normally be expected.

Minimum service temperature - The minimum temperature to which a component will be exposed in actual service, either with or without the flow of heat transfer fluid.

Mobile home - A structure, transportable in one or more sections, which is eight feet or more in width and is thirty-two feet or more in length, and which is built on a permanent chassis and designed to be used as a dwelling with or without a permanent foundation when connected to the required utilities.

Multi-family low rise dwelling - A residential multiple dwelling not exceeding four stories in height with or without elevator service. (See MPS for determination of stories.)

Multi-family high rise dwelling - A residential multiple dwelling exceeding four stories in height with or without elevator service. (See MPS for determination of number of stories.)

Operating energy - The conventional energy required to operate the H, HC and DHW systems, excluding the auxiliary energy which supplements the solar energy collected by the systems (e.g. the electrical energy required to operate the energy transport and control subsystems.)

Outgassing - The process by which materials and components expel gases.

Passive solar energy. That contribution to the building's heating and/or cooling needs which does not require external energy other than solar or the operation of the equipment included in the H or HC systems.

Pipe friction - Pipe wall roughness or duct wall roughness. Such roughness causes the loss of energy in the form of heat.

Pitting - The process by which localized wear is caused in materials or components by erosion or chemical decomposition.

Plasticizer migration - The process by which plasticizers used in plastics migrate within the specimen and either concentrate in a narrow boundary area or migrate to another material in connection with the specimen.

Ponding - The retention of water due to deflection of horizontal surfaces.

Potential heat - The difference between the heat of combustion of a representative specimen of material and the heat of combustion of any residue remaining after exposure to a simulated standard fire, determined by combustion calorimetric techniques.

pphm - Parts per hundred million.

Protective shafts - Vertical enclosures constructed of materials of the level of fire resistiveness required for the occupancy type as provided in the MPS.

Rate of heat release - A method of measuring the relative combustibility of materials by determining the rate at which heat is released by the material, as determined by calorimetric techniques.

Residual deflection - The portion of the displacement of an element in a structure which is not recovered after the removal of the action causing that displacement.

Resultant velocity of hail - The velocity resulting from a hailstone falling at its terminal velocity and acted on by a wind force.

Sensors - Devices (such as pressure transducers, thermocouples, flowmeters, etc.) used to sense individual parameters.

Service loads - Loads which are expected during the service life of a structure and upon which the design of the structure is based.

Shading angles - Angles that the sun makes in both elevation and azimuth that cause shadows.

Single family dwelling - A residential building which may be either a detached, semi-detached, duplex or row house.

Solar degradation - The process by which exposure to sunlight deteriorates the properties of materials and components.

Solar energy - The photon energy originating from the sun's radiation in the wavelength region from 0.3 to 2.7 micrometers.

Solar time - The hours of the day as reckoned by the apparent position of the sun. Solar noon is that instant on any day at which the sun reaches its maximum altitude for that day.

Storage subsystem - The assembly used for storing thermal energy so that it can be used when required.

Subsystem - One of the several major elements of a solar heating or combined heating and cooling system, such as collectors, thermal storage devices, heaters, etc.

System - The complete assembly necessary to supply heating or combined heating and cooling to the dwelling in which it is installed.

Sustained load - A load that is sustained over a period of time.

Tap temperature - The temperature at which fluid such as hot water is discharged from an outlet at the point of use.

Temperature, dry-bulb - The temperature of a gas or mixture of gases indicated by an accurate thermometer after correction for radiation.

Temperature, wet bulb - The temperature at which liquid or solid water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature.

Terminal velocity of hail - The maximum vertical velocity reached by a hailstone, occurring when the drag force on the hailstone is equal to the force exerted by gravity on its mass.

Toxic fluids - Gases or liquids which are poisonous, irritating and/or suffocating, as classified in the Hazardous Substances Act, Part 191, Chapter I, Title 21.

Transmittance - The ratio of the radiant flux transmitted through and emerging from a body to the total flux incident on it.

Ultimate strength design - A method of proportioning structures or members for failure at a specified multiple of working loads, and assuming nonlinear distribution of flexural stresses.

Utility plan - A drawing showing location of electrical lines, gas lines, water, etc.

Vertical penetrations - The vertical passage of a utility chase, pipe, duct, etc., through a fire-rated structural assembly.

Water hammer - A term used to indicate that destructive forces, exemplified by the pressure surges and attendant pounding noises and vibration which develop in a pipe system when a column of noncompressible liquid flowing through a pipe line at a given pressure and velocity is stopped abruptly.

Water hammer arrester - A manufactured device, other than an air chamber, containing a permanently sealed cushion of gas or air, designed to provide protection against excessive shock pressure without maintenance.

Working stress design - A method of proportioning structures or members for prescribed working loads at stresses well below the ultimate, and assuming linear distribution of flexural stresses.

Zero hardness - A property of softened water such that no calcium or magnesium can be detected using ordinary analytical methods.

2 1/2 percent design summer temperature - The outdoor air temperature will be higher than the stated value for not more than 73 hours per year (2 1/2% of the 2,928 hours in June through September).

97 1/2 percent winter design temperature - The outdoor air temperature will be lower than the stated values for not more than 54 hours per year (2 1/2% of the 2,160 hours in December, January and February).

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